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ABSTRACT

Fifty-five recent studies of individual differences (IDs) in elementary cognitive tasks (ECTs) are reviewed. Twenty-five data sets are examined, analyzed, or reanalyzed by factor analysis. The following promising dimensions are identified: basic perceptual processes, reaction and movement times, mental comparison and recognition tasks, retrieval and production of names and other responses from semantic memory, episodic memory tasks, and analogical reasoning and algorithmic manipulation tasks. IDs are found in both speed and accuracy in these tasks; generally, speed and accuracy are unrelated or have low intercorrelations. Considerable evidence is found for relations of ECT performances with scores on more conventional psychometric tests, but the nature of these relations is not clear, chiefly because the components of psychometric test scores have not been adequately identified in the studies. Also, the relations are complicated by the possible involvement of sex differences and differences in subjects' strategies of performance. Measures of ECT performance can supplement but not replace more conventional tests. Nearly all are visual or auditory measures. ECT's are also useful for examining psychological change, aging, and psychological theory. Sternberg's system of componential analysis can be adapted to study. (Author/CP)

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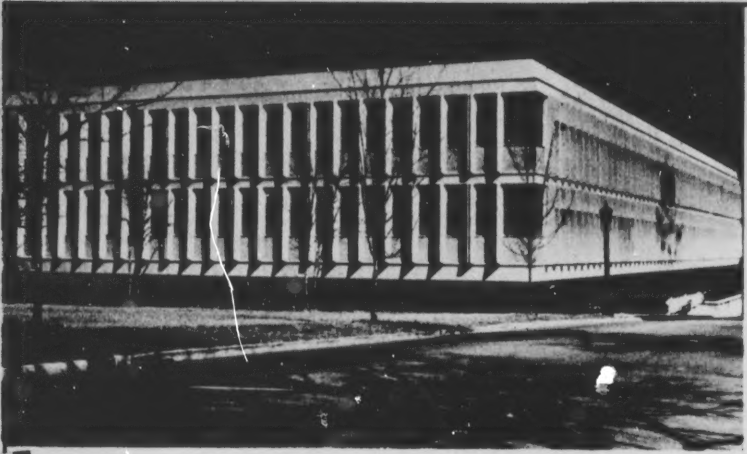

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INDIVIDUAL DIFFERENCE RELATIONS IN PSYCHOMETRIC AND EXPERIMENTAL COGNITIVE TASKS

John B. Carroll
University of North Carolina at Chapel Hill

Final Report

April 1980

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20. Abstract: A critical survey is made of recent literature pertaining to the possibility of measuring important dimensions of human cognitive ability through various types of simple cognitive tasks. The monograph is an expansion of a portion of the review by Carroll and Maxwell (1979) of human cognitive abilities published in the Annual Review of Psychology. The survey focuses on individual differences (IDs) found in cognitive tasks that have received extensive study in experimental cognitive psychology--for example, simple and choice reaction time, lexical decision, stimulus matching, probed search of short-term memory, memory span, free and serial recall, simple sentence comprehension, and analogical reasoning. Questions of paramount interest were: What kinds of individual differences are observed in these tasks? Do they exhibit sufficient variance and reliability to measure stable individual characteristics that may be of relevance in personnel selection and other operational contexts? What are the dimensions of these IDs from a factor-analytic standpoint? How are they related to those observed through more conventional psychometric tests? To what extent are they subject to the effects of practice and specific training, or related to demographic variables in such a way as to reduce their utility for operational use? Can the study of individual differences in simple cognitive tasks be valuable in the development of psychological theory?

A considerable portion of the monograph is devoted to the definition and specification of "elementary cognitive tasks" (ECTs) and to how ECTs can be administered, in experimental settings, so as optimally to reveal IDs in cognitive processes. A scheme for classifying ECTs according to basic paradigms is presented, and suggestions are made concerning procedures, including computer simulation, for conceptualizing and analyzing underlying processes.

With these theoretical considerations as background, 55 recent studies relevant to IDs in ECTs are reviewed. Some 25 data sets are examined and in many cases analyzed or reanalyzed by factor analysis. Promising dimensions of IDs are identified in the following domains: basic perceptual processes, reaction and movement times, mental comparison and recognition tasks, retrieval and production of names and other responses from semantic memory, episodic memory tasks, and analogical reasoning and algorithmic manipulation tasks. IDs are found in both speed and accuracy in these tasks; generally, speed and accuracy are unrelated or have low intercorrelations. Considerable evidence is found for relations of ECT performances with scores on more conventional psychometric tests, but the nature of these relations is not clear, chiefly because the components of psychometric test scores have not been adequately identified in the studies. Also, the relations are complicated by the possible involvement of sex differences and differences in subjects' strategies of performance.

It is concluded that measures of performance in ECTs have much promise as supplements to more conventional tests, but probably not as replacements for them. ECT performances are also believed to be useful in assessing the effects of physiological changes, and of aging. The study of IDs in ECT performances is found to be valuable also in the development of psychological theory. Proposals are made concerning how R. Sternberg's (1977) system of componential analysis can be brought within the framework of more traditional psychometric procedures in the study of IDs. The study of IDs in ECT performances is asserted to be an extremely profitable field for further research.

INDIVIDUAL DIFFERENCE RELATIONS IN PSYCHOMETRIC AND EXPERIMENTAL COGNITIVE TASKS

John B. Carroll

Report No. 163
The L. L. Thurstone Psychometric Laboratory
University of North Carolina
Chapel Hill, N. C. 27514
April 1980

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PREFACE AND ACKNOWLEDGMENTS

This is the final report of Project NR 150-406, "An integrative review of recent research on individual differences in cognitive performance," sponsored by the Personnel and Training Research Programs, Office of Naval Research under Contract No. N00014-77-C-0722.

During the period of the research, which began August 1, 1977, activities under the project have consisted chiefly of the collection, analysis, and review of pertinent literature.

A Technical Report (No. 1), written by J. B. Carroll and issued in January 1978 was entitled "How shall we study individual differences in cognitive abilities?--Methodological and theoretical perspectives." It was subsequently published in Intelligence, 1978, 2, 87-115, and reprinted in R. J. Sternberg and D. K. Detterman (Eds.), Human intelligence: Perspectives on its theory and measurement (Norwood, N.J.: Ablex, 1979), pp. 3-31.

An intermediate goal of the project was the preparation and publication of a review chapter, "Individual differences in human cognitive abilities," by John B. Carroll and Scott E. Maxwell, in the Annual Review of Psychology, 1979, 30, 603-640.

Through the participation of the principal investigator in several conferences and conventions, other publications and presentations resulting from the project or related to it are as follows:

Carroll, J. B. Discussion: Aptitude processes, theory, and the real world. In R. E. Snow, P.-A. Federico, & W. E. Montague (Eds.), Aptitude, learning, and instruction, Vol. 1: Cognitive process analyses. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1980, pp. 139-148.

Malmi, R. A., Underwood, B. J., & Carroll, J. B. The interrelationships among some associative learning tasks. Bulletin of the Psychonomic Society, 1979, 13, 121-123.

Carroll, J. B. A first principal component does not necessarily indicate a g factor: Remarks on Jensen's data and g factor computations. Presented at the meeting of the Society for Mathematical Psychology, Providence, R.I., August 1979.

Carroll, J. B. Comments on papers by D. Thissen and by K. Tatsuoka. Presented at the 1979 Conference on Computerized Adaptive Testing, University of Minnesota, June 1979.

Carroll, J. B. Measurement of abilities constructs. Presented at the Construct Validity Colloquium, Educational Testing Service, Princeton, N.J., October 1979.

Carroll, J. B. Ability and task difficulty in cognitive psychology. Presented at the convention of the American Educational Research Association, Boston, Mass., April 1980.

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I wish to express appreciation to John Frederiksen, Earl B. Hunt, Mark D. Jackson, Robert J. Sternberg, and Thomas S. Wallsten for furnishing helpful comments on certain portions of a draft of the report. Any errors of reporting, analysis, or interpretation are to be attributed solely to me, however.

Indeed, I feel impelled to issue at this point a strong cautionary statement about the findings and conclusions of this report, analogous to the notice that is sometimes stamped or imprinted on computer program documents, "THIS PROGRAM IS NOT GUARANTEED TO BE FREE OF ERROR." The report is written by a person who has much less training and experience in experimental cognitive psychology than in the field of psychometrics. I am not completely conversant with the vast literature that has dealt with issues in cognitive psychology. Consequently, despite my best efforts, it is quite possible and even probable that at least some statements and opinions expressed in this report about issues in cognitive psychology are misguided or flatly wrong, and in conflict with well established knowledge that can be found in the literature of the field. It is hoped that any errors, incorrect statements, or misguided opinions will not seriously mislead the careful student who is attentive to the specialized literatures in different areas of cognitive psychology.

I would cheerfully welcome any constructive criticism or corrections that readers may offer, since it is my intention to pursue this field further in research and writing.

John B. Carroll

April 1980

Chapter 1

INTRODUCTION

Background

Stemming from proposals and exploratory research by such investigators as Hunt, Frost, and Lunneborg (1973), Estes (1974), Underwood (1975), R. Sternberg (1977), and others, the Personnel and Training Research Program of the Office of Naval Research has recently shown much interest in supporting research aimed at examining the possibility of measuring important dimensions of human cognitive ability through various types of relatively simple cognitive tasks. These tasks have included (among others) the following: simple and choice reaction tasks, naming and word-reading tasks, iconic memory tasks, simple comparisons of stimuli with respect to physical, graphemic, and semantic characteristics, probed search of short-term memory, visual scanning tasks, mental addition, recognition tasks (discrimination of previously presented items from ones not previously presented in a laboratory learning situation), memory span and other serial and free recall tasks (with or without a phase in which interference with memory for the presented stimuli is introduced), paired associate learning tasks, simple language comprehension tasks, and simple reasoning tasks (such as analogical reasoning and three-term series problems). Individual differences (hereafter, IDs)* measured through such tasks might have use in personnel selection and in various aspects of personnel training programs. It is thought that IDs measured in performance of tasks would be less subject to the possibly biasing effects of differences in education, training, special knowledge, special opportunities for practice, and other variables that are thought to lessen the validity and/or "fairness" of more conventional psychometric procedures. If some set of experimental cognitive tasks could be developed to the point of attaining high reliability, validity, and standardization, it is believed, they could be substituted for more conventional tests, or at least used as important supplements to such tests.

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*Throughout this report, abbreviations for terms and phrases frequently used are as follows: ETS, Educational Testing Service (Princeton, NJ); FA, factor analysis, factor-analytic; GRE, Graduate Record Examination; ID, IDs, individual difference(s); IQ, intelligence quotient; PA, paired associate(s); PMA, Primary Mental Abilities; RT, reaction time; SAT, SAT-V, SAT-M, Scholastic Aptitude Test (-Verbal, -Mathematical); SES, socioeconomic status; SI, structure of intellect; WAIS, Wechsler Adult Intelligence Scale; WISC, Wechsler Intelligence Scale for Children.

Although some of this work has a practical orientation, it is also recognized as possibly important in leading to a better theory of what is traditionally referred to as "intelligence," and to a better understanding of the nature of individual differences in cognitive abilities. Estes (1974), Hunt and Lansman (1975), and Underwood (1975) have underlined the potential usefulness of ID research in the development of psychological theory.

Focus of the Present Study

The present study is frankly a survey and critique of literature. It presents no new data (except, perhaps, in the course of reanalyzing data presented in the literature). A comprehensive and critical survey of the kind undertaken here has not, to our knowledge, been undertaken previously.

In the course of this literature survey, the following questions will be uppermost:

1. What kinds of IDs are observable in simple cognitive tasks?

2. Are these IDs of sufficient extent, and can they be made to attain sufficient reliability, to lead one to believe that they reflect stable characteristics of individuals, and to suppose that they might be relevant in personnel selection and training programs in an organization like the U.S. Navy?

3. How can these IDs best be observed? Under what conditions, and through what procedures, can they best be measured? How should performances be scored and otherwise reduced to quantitative terms? Are the IDs reflected better in gross speed and accuracy scores, or are they better reflected in carefully defined parameters of task performance in relation to information processing theories? Are "componential analysis" procedures (as suggested by Sternberg, 1977) to be recommended in obtaining suitable performance measures, and if so, how generally can such procedures be applied?

4. From a factor analytic viewpoint, what are the dimensions of IDs in simple cognitive tasks? How general are these dimensions over a wide variety of such tasks, or is it the case that IDs are largely specific to narrowly defined classes of tasks?

5. To what extent do IDs measured through simple cognitive tasks relate to dimensions of IDs as measured by more conventional psychometric tests? To what extent, if at all, are these IDs involved in the performance of more conventional tests, and if so, can conventional tests be adapted so as to better reflect the functioning of such IDs? If there are significant relationships between IDs measured through simple cognitive tasks and those measured through more conventional tests, do these relationships reflect intrinsic common elements between the two classes of variables, or do they reflect the operation of extrinsic, "third variables"?

6. To what extent are IDs measured through simple cognitive tasks subject to the effects of specific education, training, practice, and other variables that would tend to reduce their suitability for use in personnel assessment and training programs? To what extent do they vary as a function of such demographic variables as sex, age, SES, race, and occupation? To what extent do they vary as a function of strategies of performance that may be more or less arbitrarily chosen or adopted by examinees?

7. To what extent, and in what way, is the study of IDs in simple cognitive tasks likely to lead to better understanding of human behavior, or to the development of psychological theory? What is the "construct validity" of these IDs, i.e., what do they "really" measure or reflect?

Scope of the Literature Surveyed

Cognitive psychology is currently a rapidly burgeoning field, but it has focused on a relatively small number of experimental "paradigms" such as choice reaction time, comparisons of stimuli (e.g., the type of task studied by Posner and his associates [Posner & Mitchell, 1967]), probed search of short-term memory (as studied by S. Sternberg, 1966), memory span, free and serial recall, sentence comprehension (as studied by Clark & Chase, 1972), and analogical reasoning (R. Sternberg, 1977; Whitely, 1976). Many of these tasks have been intensively studied by experimental psychologists, though not usually with the objective of identifying and studying IDs. In the present survey, an attempt is made to examine a wide variety of these paradigms, and the tasks associated with them, from the standpoint of their potential use in ID research. Through the tracking of the numerous journals in the field of cognitive psychology, and by the use of divers bibliographic sources, a large file of references has been assembled* that, it is believed, includes an adequate representation of the variety of paradigms and tasks that have been studied in cognitive psychology in recent years. Since some of these paradigms and tasks have actually been objects of study for a very long time, the bibliographical coverage has extended fairly far back into the history of experimental psychology, even into the late 19th century.

Equal attention has been given also to the collection of literature concerned with the identification of IDs in the psychometric tradition, particularly that of factor analysis. The bibliographic coverage has included work not only in the measurement of general, verbal, and non-verbal intelligence, but also factor-analytic work following traditions established by Thurstone (1938), Guilford (1967), Cattell (1971), and Horn (1965).

The reference file further contains many citations of articles, manuscripts, books, monographs, etc. discussing cognitive theory, the theory of IDs in cognitive abilities, the possible genetic and environmental determinants of such differences, and methodological problems arising in ID research.

The literature review itself is selective in a way that cannot be precisely specified beyond the statement that the reviewer has used his experience and judgment to choose materials from the literature data base that are deemed most pertinent to the objectives of the survey. Because of space and time limitations, many materials and issues cannot be dealt with extensively, if at all.

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*At the present writing, this file contains 2732 items that are maintained in two forms: (1) a 5 x 8 card file, alphabetically arranged by authors, that contains (in many cases) abstracts, notes, and other annotations; and (2) a computerized file of the reference citations from which various sorts by author, title, date, subject-matter classification, and source can be printed. The file is being continually updated and added to.

Some Perspectives and Constraints

The stance adopted here is that of a "hard-nosed," critical examination of the literature from the standpoint of its adequacy, in terms of experimental and psychometric methodology, for answering the questions posed. The initial assumption is in the form of a null hypothesis to the effect that IDs observed in simple cognitive tasks are of no theoretical or practical importance, and that they have no intrinsically meaningful relationships to the IDs measured by conventional psychometric tests. Compelling evidence is sought that might lead one to reject such a null hypothesis. Selected studies are examined in considerable detail; in some cases, data are reanalyzed and the results of different studies are compared. Flaws thought to be present in the design, execution, and analysis of studies found in the literature are pointed out whenever necessary. When appropriate, the reviewer makes recommendations as to what he regards as preferred procedures of design, execution, and analysis.

In the main, the focus is on studies done with "adult" subjects (late adolescence and early adulthood). Studies involving children, or older adults, are discussed only when their results are believed to illuminate those of studies done with younger adults.

There will be little discussion of problems of the predictive or concurrent validity of IDs in simple cognitive tasks vis-à-vis training or job success criteria. There are, in any case, few studies in which pertinent data on these problems are to be found, and even if the literature contained sufficient information on these points, considering them would too much enlarge the scope of this review. However, the reader will find discussion of the "construct validity" of these IDs, i.e., the nature of the abilities and individual characteristics that they may reflect.

A somewhat neutral, eclectic, and atheoretical stance is adopted regarding what is meant by such terms as "ability," "aptitude," and "achievement." If the focus is primarily on IDs observed in individuals' performances in simple cognitive tasks, it is only for further consideration and research to determine whether these IDs reflect relatively enduring and persistent characteristics of individuals as opposed to relatively transitory attributes, and whether these IDs arise through genetic influences or long-term maturational effects as opposed to the effects of education, training, and specific experiences. In some cases, e.g. performance on word-recognition tasks, IDs are obviously at least partly a function of long-term educational experiences, and could well be related to scores on tests of educational achievement such as reading comprehension tests. Although one might be inclined to exclude consideration of IDs in such types of educational achievement, they are nevertheless discussed here, along with IDs the status of which with regard to specific environmental effects (e.g., those observed in choice reaction time tasks) is much less clear. We draw the line only with respect to tasks that can be successfully performed only by persons with quite specific kinds of education and training, e.g., tasks whose performance requires knowledge of a foreign language, of certain scientific concepts, or of other subjects that are taught only to certain individuals in school.

General Plan of the Review

As already noted, the focus of the review is on IDs observed in what are referred to as "simple cognitive tasks." This necessitates defining this phrase and delimiting the range of tasks that might be included under this rubric. A method of describing and analyzing such tasks is presented so that they can be compared, classified, and examined from an information processing perspective. The concept of an "elementary cognitive task" (ECT) is developed, and a method of graphically representing the structure of an ECT--the method of "dual time representation" (DTR)--is presented, leading to analysis of stages, components, and parameters of ECTs. A computer program, SIMCOG, for representing the structure of ECTs is also presented.

With these theoretical developments as background, a series of simple cognitive tasks examined in recent cognitive psychology literature are described and analyzed in the ECT, DTR, and SIMCOG frameworks. Evidence for ID variance in the performance of such tasks is reviewed extensively.

Next, the dimensionality of these IDs and their relations to IDs observed in more conventional psychometric tests are considered. It is found necessary to analyze selected psychometric tests in the ECT, DTR, and SIMCOG frameworks, and to explicate the relations of test scores to the stages, components, and parameters of the tasks included in these psychometric tests. As far as available evidence permits, the dimensionality of IDs in both ECT and psychometric tests is assessed from a factor analytic standpoint, i.e., setting forth what general, group, and specific factors are to be found in this domain.

Various issues relevant to the IDs in ECTs and psychometric tests are then considered in detail, including their reliability, their construct validity, and their susceptibility to education, training, and practice effects. The role of subjects' performance strategies in modulating the effects of IDs is also discussed.

The results of the survey are summarized according to the list of questions posed in an earlier section of this introduction.

Chapter 2

PARADIGMS AND PROCESSES OF COGNITIVE PSYCHOLOGY

The Need for a Systematic Theory of Cognition

Eloquent pleas for a satisfactory theory of cognition, as it might be applied in the study of IDs, have already been sounded by Hunt and others (Hunt, Frost, & Lunneborg, 1973; Hunt & Lansman, 1975). The need becomes more evident as one approaches the task of analyzing the current literature for information about ways in which IDs manifest themselves in the cognitive tasks studied by experimental psychologists, and the manner in which they are revealed in psychometric tests. The literature of cognitive psychology is still extremely fragmented. A large number of types of cognitive tasks have been studied, and several models of cognitive processes have been proposed. Yet, there seems to be no theory that allows one to classify cognitive tasks according to a unified scheme and to interpret them as reflecting specifiable components of an integrated model. One has the impression that the many studies of particular cognitive tasks give no way of interrelating them. Furthermore, there is no agreed-upon list or array of cognitive processes by which one can analyze the covert and overt behavior of human performers of those tasks. Newell and Simon (1972, pp. 29-30) have proposed one such set, but the formalization and adequacy of this set has not yet been tested. It is therefore difficult to cross-identify the sources of IDs observed in those tasks.

This chapter attempts to develop at least a first approximation to a unified theory of cognitive processes. It can be only a brief sketch indicating the directions in which we are thinking; it has to ignore much of the extensive experimental literature on cognitive processes. First we attempt to classify what we will call elementary cognitive tasks (ECTs). In order to achieve this classification, it is found desirable to propose a tentative classification of the major paradigms of cognitive psychology. Based on the analysis of these paradigms and the cognitive tasks they represent, a list of distinct cognitive processes is drawn up, and each postulated cognitive process is given a formal characterization. Two ways of analyzing cognitive tasks in terms of these processes are presented and illustrated: (1) a graphical method, called Dual Time Representation (DTR), and (2) a computer program, called SIMCOG, that affords a limited type of simulation of cognitive processes in cognitive tasks. The use of the several paradigms in observing and measuring distinct cognitive processes is described as a background to the survey of literature of IDs in cognitive tasks that is made in the following chapters.

Elementary Cognitive Tasks: Toward a Definition

In the introductory chapter, we have rather casually spoken of a variety of "simple cognitive tasks" without defining this term. In the interest of delimiting and characterizing the objects that this survey covers, and also in the interests of specifying the characteristics of those objects in relation to a theory of behavior and cognitive performance, we find it desirable to attempt to establish a special definition of what we shall term an elementary cognitive task (ECT).

Dictionary definitions of the word task* do not adequately convey the characteristics and structure of what is intended by the term ECT, and some connotations of the word (its association with the notion of work, the assignment of tasks by superiors, and the difficulty, tediousness, and/or aversiveness of tasks) are irrelevant. We may define a task as any action that a person may undertake in order to achieve a specifiable class of objectives, final results, or terminal states of affairs. It is to be understood, however, that "finality" is only relative; the end result or terminal state may only lead to another task, either a repetition of the same task or to a different one. The specifiability of the end result of a particular task is crucial, however, first because the individual undertaking the task must understand what type of end result is to be attained and have some notion of the criterion or criteria by which attainment of the end result is to be assessed. Because of this, the term "cognitive" could be regarded as automatically entailed in the definition of the term task. From this standpoint, the task of, say, digging a round hole in the ground one foot deep and one foot in diameter could be said to be a cognitive task, because the person undertaking to dig such a hole must understand (among other things) what a hole is and how the dimensions of the hole are to be measured.

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*American College Dictionary (Random House): "1. a definite piece of work assigned or falling to a person, a duty; 2. any piece of work; 3. a matter of considerable labor or difficulty." American Heritage Dictionary: "1. A piece of work assigned by a superior or done as a part of one's duties. 2. A difficult or tedious undertaking. 3. The function that a working person, unit, or thing is expected to fulfill; objective."

By using the adjective cognitive, we intend to limit the range of "cognitive tasks" to those which centrally involve mental functions not only in the understanding of the intended end results but also in the performance of these tasks. Performing the task of digging a hole in the ground implicates mental functions to a relatively limited extent; the task of repeating a series of numbers (as in a memory span task) involves mental functions (storing and retrieving the numbers with respect to their order of appearance, in addition to "chunking" or otherwise manipulating the materials to be repeated) in its performance, and therefore can be called a "cognitive" task. Even though an ECT may (as it nearly always does) involve a motor performance (pressing a button, moving a finger, uttering a word, etc.), it is cognitive to the extent that decision processes direct these motor performances.

We may also assert that a task becomes cognitive to the extent that, given the same stimulus and situation in which to operate, different performances and different end results are a function of the instructions given to, or self-adopted by, the performer prior to the action. For example, given a series of digits to repeat, a person would be expected to respond differently depending upon whether he is instructed to repeat the digits in the same order as presented, or backwards, or with the addition of a constant to each number.

By using the attributive elementary, we intend further to restrict the range of "elementary cognitive tasks" to those which require, in their performance, a relatively small number of mental processes acting either sequentially or simultaneously. Finding one word to fulfill the requirements for one row or column of cells in a crossword puzzle would be regarded as an ECT. Completing the whole of the puzzle would not;

rather, it would be regarded as a series of separate ECTs, amenable to being performed in various orders and with different stimulus conditions, depending on the order in which they are performed. Mentally dividing a 2-digit number by a 1-digit number could be an ECT; but it is unlikely that mentally dividing a 10-digit number by a 3-digit number would be regarded as an ECT. Repeating a 10-word sentence after an experimenter could be regarded as an ECT, but summarizing the content of a presented 100-word paragraph probably would not.

The attribute of being "elementary" is a matter of degree and no sharp demarcation of ECTs can be made in this respect. The ECTs studied in cognitive psychology are characteristically simple rather than complex. "Complex" cognitive tasks, such as summarizing a paragraph, could in theory be reduced to series of ECTs but their complexity would reside in the very large number of possible patterns and sequences of ECTs that a subject could go through in the performance of the task as a whole.

It is also characteristic of ECTs that their end results are highly determinate in the sense that achievement of the final state or outcome can be readily judged as successful or "correct." A subject's judgment of whether two stimuli are the "same" or "different" can be assessed as either "correct" or "incorrect" depending on the actual objective comparison of the stimuli. Achievement of a "successful" final state is possible in an ECT even when (as in the task of finding a synonym for a word, let us say) any one of a number of possible outcomes could be judged "adequate" or "correct" completions of the task. In the case of a free association task (responding to a stimulus with "the first word that comes to mind"), the criterion for judging a response as "adequate" could be as loose as requiring simply that any word is an adequate response, as long as it is different from the stimulus, or otherwise non-routine.

In view of the problems encountered in strictly defining an ECT, we offer only the following tentative and somewhat loose definition:

> An elementary cognitive task (ECT) is any one of a possibly very large set of tasks in which a person undertakes, or is assigned, a performance for which there is a specifiable class of "successful" or "correct" outcomes or end states which are to be attained through a relatively small number of mental processes or operations, and whose successful outcomes can differ depending upon the instructions given to, or the sets or plans adopted by, the person.

This definition will perhaps become further specified through the examination and analysis of a series of ECTs which have been studied in cognitive psychology and which conform to our general concept of elementary cognitive task.

Defining ECT will also be facilitated by the realization that in many cases, the "items" contained in mental ability tests can be regarded as ECTs.

The Classification and Analysis of ECTs

It is an avowed purpose of cognitive psychology (Neisser, 1967) to study mental processes, that is, mental operations that involve the processing of information. In the course of research in this field, a number of experimental "paradigms" have been developed, the purpose of which is to permit the isolation of mental processes of interest and the determination of how the operation of these processes is affected by experimentally manipulating variables such as stimulus presentation duration, type of stimulus, task instructions, etc. Among the paradigms that have been developed and studied intensively are the "Posner task" (Posner & Mitchell, 1967), the "Sternberg paradigm" (Sternberg, 1966), the memory span paradigm, the free recall paradigm, and the Clark and Chase (1972) sentence verification paradigm. In general, these paradigms represent classes of ECTs. An ECT requires a greater amount of specification than a paradigm. Whereas a paradigm implies only a very general specification of the structure and design of an experimental task, and admits of many variants, any given ECT requires the specification of the instructions given, the types of stimuli presented, the temporal relationships involved, the responses required, etc. A standard method is needed for specifying ECTs and for distinguishing highly similar ECTs. Even when two ECTs appear to conform to the same paradigm, there can be subtle differences between them that may affect findings and results in a radical way.

On the other hand, the several experimental paradigms developed in cognitive psychology may not always be as distinct as they might appear to be merely from the fact that they are designated differently. For example, the serial recall paradigm is highly similar to the memory span paradigm, since both involve a "readout" of stored memories in the order in which their stimuli are presented. Likewise, the "Stroop task" (Stroop, 1938) has many features in common with naming and reading tasks. It therefore becomes desirable to establish a system for comparing and classifying paradigms, and for relating them to the ECTs that may be generated from them.* Proposals toward this goal are contained in the following sections.

Dual Time Representation (DTR) of ECTs

In presenting the structure of an experimental task or paradigm, authors sometimes utilize a graphical, diagrammatic representation in which the sequence of events is shown from left to right or from above to below. We have found it useful to elaborate this type of presentation by showing time on both left-to-right (horizontal) and above-to-below (vertical) axes. We call this type of diagram dual time representation, or DTR.

In this representation, objective (observable) stimulus and response events are shown along the central time axis that runs from upper left to lower right. The remaining space in the chart is available for other purposes. The upper triangle (above the diagonal axis) is used for representing presumed mental or "cognitive" processes, their duration and effects over time, and their interrelationships and interactions with stimulus and response events and with each other. The lower triangle can be used for such purposes as annotating stimulus variations, depicting repetitions of events (as by the "repeat signs" of musical notation), and showing measurement procedures (e.g., time measurements). The distances on a DTR chart are regarded only topologically; i.e., they show only temporal order relationships among events, but do not necessarily represent, to scale, the exact occurrence times or the durations of events.

Various further conventions can be established in designing DTR charts. In representing objective events, those that are obligatory (i.e., that are always present and are characteristic of the task) are shown in solid-line boxes. Optional events are shown in broken-line boxes. Broken lines bordering the lower right of a box can be used to indicate that an event (e.g., the shining of a light) persists for an indefinite period, or until some other event supercedes it. A box of either type can be filled with an abbreviated description of the events it represents; further details can be placed in the lower triangle of the chart, in the form of footnotes. If two or more events are simultaneous, they can be shown by dividing the box into horizontal sections and allocating appropriate space to each event. (If the same time scale is used in both vertical and horizontal dimensions, the boxes are square, but it is usually more convenient to foreshorten the vertical dimension relative to the horizontal, in which case the boxes become rectangular.)

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*To our knowledge, there have been few if any systematic attempts to establish schemas for classifying and comparing paradigms and cognitive tasks. Donders (see Chase, 1978, pp. 21-23; Scott, 1940) proposed a tentative scheme for classifying certain reaction time tasks. Melton (1964) edited a series of papers that attempted to establish "categories of learning," but the book did not result in any commonly accepted classification system.

"Cognitive" (non-observable, but presumed) events may be shown in "cartouches" placed in the upper triangle of the chart in such a way as to show assumed precursors and consequences of such events and their temporal relationships. (Cartouches are boxes of a generally rectangular shape but with rounded corners.) Lines, generally with direction of effect shown by arrows, show presumed causal connections and interactions of cognitive events with objective events and with each other.

A DTR chart can include some of the features of the more conventional flow diagrams that are often used to depict presumed flows of cognitive processes, but in the DTR chart a distinction is made between objective and cognitive events by using different areas to represent them. Flow diagram conventions usable in DTR charts could include representations of tests of conditions and the consequences of decisions.

To illustrate this mode of representation and its possible advantages, we show a DTR for a comparatively simple type of ECT in the choice reaction time paradigm, and one for a relatively complicated type of ECT, the analogical reasoning task. First let us consider DTRs for the choice reaction time paradigm. Two variants are shown, to illustrate the power of the DTR to depict small differences in procedure that can make for differences in results. Figure 1 shows a choice reaction time ECT as realized in the task used by Keating and Bobbitt (1978, pp. 157-158).

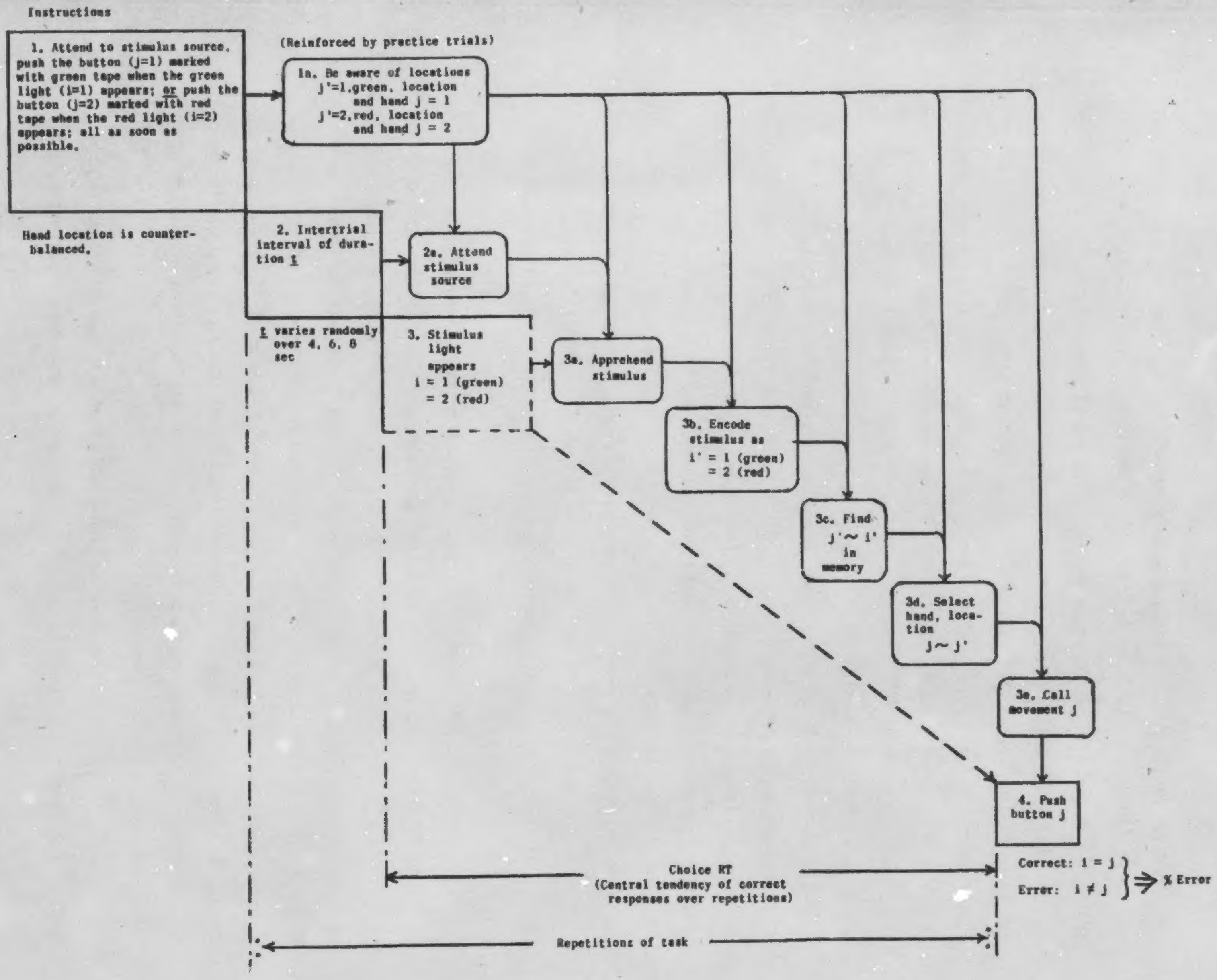
Instructions
1. Attend to stimulus source, push the button (j=1) marked with green tape when the green light (i=1) appears; or push the button (j=2) marked with red tape when the red light (i=2) appears; all as soon as possible.
(Reinforced by practice trials)
1a. Be aware of locations j'=1, green, location and hand j = 1 j'=2, red, location and hand j = 2
Hand location is counter-balanced.
2. Intertrial interval of duration t
2a. Attend stimulus source
t varies randomly over 4, 6, 8 sec
3. Stimulus light appears i = 1 (green) = 2 (red)
3a. Apprehend stimulus
3b. Encode stimulus as i' = 1 (green) = 2 (red)
3c. Find j' ~ i' in memory
3d. Select hand, location j ~ j'
3e. Call movement j
4. Push button j
Choice RT (Central tendency of correct responses over repetitions)
Correct: i = j
Error: i ≠ j
⇒ % Error
Repetitions of task

FIGURE I

Each box or cartouche is labeled with a number (and a letter, in the case of cartouches). Box (1) at the upper left specifies the instructions for the task, not ordinarily in the exact words in which they are given in practice, but in a form that conveys their essential features. Simple mathematical notation is used to formalize the fact that two colors of lights are possible and that each light is associated with a particular location (left or right, and as marked with green or red tape). The fact that S must be aware of these associations throughout the task (and the experiment) is symbolized by cartouche (1a), and the effects of this awareness throughout the task are shown by lines connecting this cartouche to others. A note on the chart indicates that this awareness is learned and reinforced through practice trials.

The next objective event is an intertrial interval of duration $\underline{t}$, varying randomly over 4, 6, and 8 seconds. Accompanying this event is an assumed attentional process specified in cartouche (2a). Following is the appearance of a stimulus light, its color being either green or red; this is specified in box (3). The lower right of this box is outlined with a broken line to indicate that this particular event persists for an indefinite period; in this particular case, it persists until the next objective event (box 4) occurs, i.e. the subject's response in the form of a button push by either the left or the right hand.

Event 3, however, is assumed to trigger a series of cognitive events specified in cartouches (3a-e). (3a) is apprehension of the stimulus, i.e., recognition of the stimulus as a stimulus, but without its identification or encoding, a process specified in (3b). Encoding of the stimulus as $i' = $ (green, red) is assumed to involve some kind of memory access. The prime on i' denotes representation in memory. Further memory access is involved in (3c), where the stimulus is matched with its location/hand, j'; again, the prime on j' denotes memory representation. Process (3d) translates the result of the match to the appropriate hand, j, and process (3e) calls a movement of hand j that results in the botton push, box (4).

Ideally, one would like to have available ECTs that would permit assessing the temporal and other characteristics of each of the mental processes represented in cartouches here. Some of these processes can in fact be studied with other ECTs and paradigms; for example, the apprehension process can be studied with the sensory threshold apprehension paradigm (see p. 23) involving time-intensity relations see Blumenthal, 1977, pp. 34-37, on Bloch's law), but this paradigm has not generally been used in studying IDs and will not be presented here. As this ECT stands, it can be used only for measuring total choice reaction time, as shown in a line that extends (horizontally) from the onset of the stimulus to the button push. This choice reaction time must be assumed to be the summation of the times for the five processes (3a-e). But a further qualification has to do with the correctness of the response; generally, choice RT is measured only for correct responses, i.e., where i = j. Also, the choice reaction time is usually obtained through some kind of central tendency measure over repeated tasks; the task repetition feature is shown by a line towards the bottom of the chart with "repeat" signs at its terminal. The additional measure obtainable from this task is represented by the percent of error, shown at the lower right.

Now consider the ECT for the choice reaction task studied by Jensen (1979), represented in DTR form in Figure 2. Since no new conventions of representation are introduced, the chart should largely explain itself. Comparison with Figure 1, however, shows that several complications have been introduced into the task. There are two separate interstimulus intervals, each with its own process of attention. Process (3a) requires a wider span of attention, upon up to 8 possible stimulus sources, than process (2a) of Figure 1, which focuses on only one stimulus source. Process (5a) of Figure 2 is similar to process (3a) of Figure 1, and process (5b) is analogous to process (3b) of Figure 1 if account is taken of varying set sizes in Figure 2. (Distinguishing colors, however, may be a different process from distinguishing positions of lights.) Process (5c) is possibly fundamentally different from process (3c) of Figure 1, because the latter requires retrieving the correspondence j' ~ i' from memory, whereas the correspondence is trivial in Figure 2. That is, the subject has little problem in remembering where the response is to be made. (The experiment could, of course, be complicated by altering this rule, such that, for example, j' ~ (i' + 1),

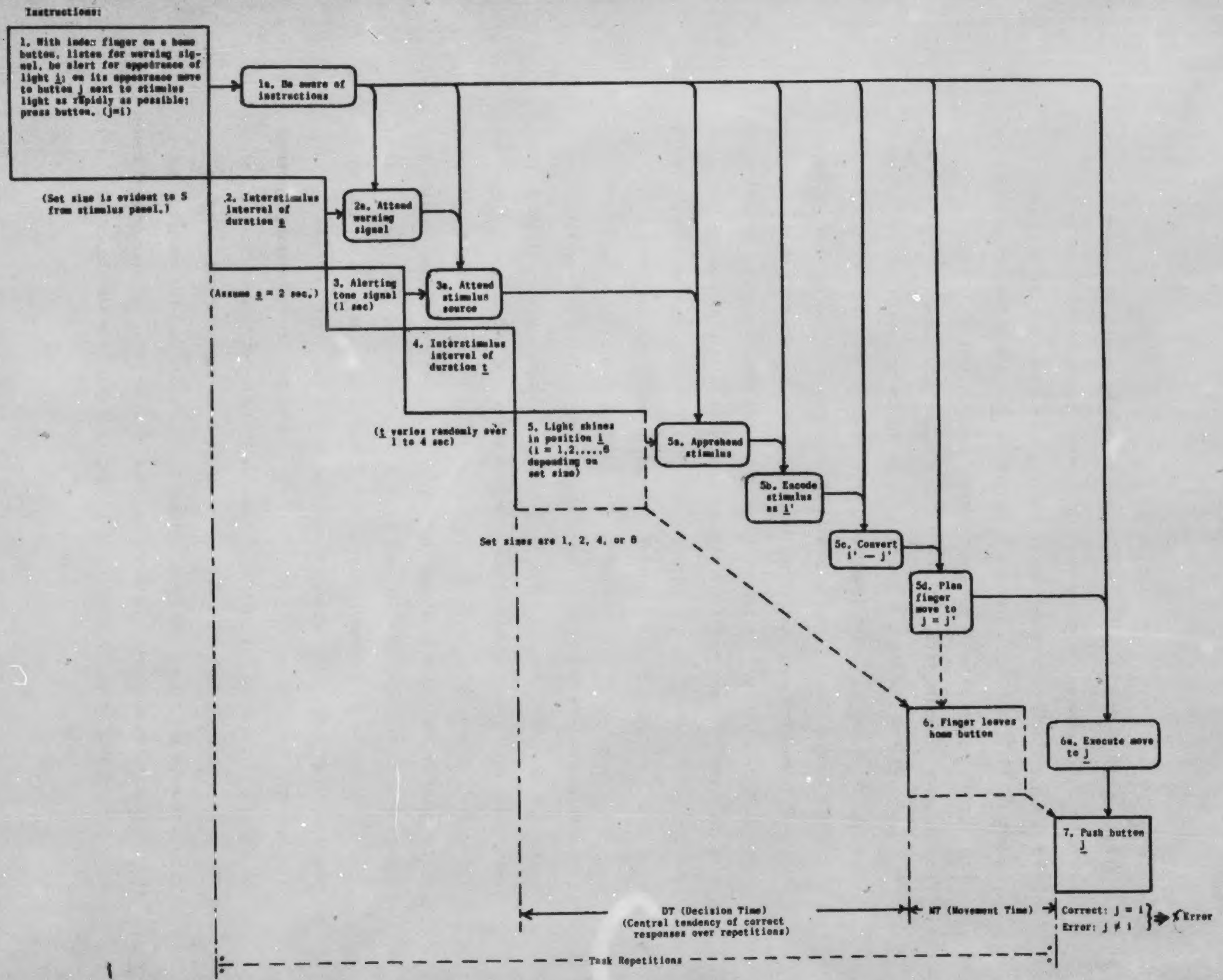
Instructions:
1. With index finger on a home button, listen for warning signal, be alert for appearance of light i; on its appearance move to button j next to stimulus light as rapidly as possible; press button. (j=i)
1a. Be aware of instructions
(Set size is evident to S from stimulus panel.)
2. Interstimulus interval of duration s
2a. Attend warning signal
(Assume s = 2 sec.)
3. Alerting tone signal (1 sec)
3a. Attend stimulus source
4. Interstimulus interval of duration t
(t varies randomly over 1 to 4 sec)
5. Light shines in position i (i = 1,2,....,8 depending on set size)
5a. Apprehend stimulus
5b. Encode stimulus as i'
5c. Convert i' — j'
5d. Plan finger move to j = j'
Set sizes are 1, 2, 4, or 8
6. Finger leaves home button
6a. Execute move to j
7. Push button j
DT (Decision Time) (Central tendency of correct responses over repetitions)
MT (Movement Time)
Correct: j = i
Error: j ≠ i
Error
Task Repetitions

FIGURE 2

whereby one would always move to the next button to the right of the lighted stimulus.)

An interesting feature of the Jensen version of this task is that it permits distinguishing reaction time (or as I would prefer to call it, decision time) from movement time. Thus, any time taken with the execution of the finger move (6a) is measured separately from decision time; decision time does however include process (5d), the planning of the finger move.

In any case, it is apparent that reaction time measurements with the Jensen version of the task incorporate different processes and thus may be expected to be systematically different from reaction times measured with the Keating and Bobbitt version. Although it is impossible to derive truly comparable data from the two experiments, the total reaction times from them do appear to be systematically different. For more or less comparable subject groups (college adults), the Jensen values are higher for a two-choice response when movement times are included, but lower when movement times are excluded, than corresponding values in the Keating and Bobbitt data.

Figure 3 shows a DTR of the analogical reasoning tasks studied by R. Sternberg (1977). The analysis made here is slightly different from Sternberg's, and it discloses several questions that could be raised about his analysis. One new convention introduced in this DTR is the use of brackets around boxes to indicate experimental variations. These variations are associated with Sternberg's use of varying numbers of "cues," i.e. varying numbers of terms in the analogy before the subject makes an initial response, to be followed by presentation of the remaining terms to evoke the subject's further response. Another convention introduced is the use of numbers to label alternative possible routes. In our analysis, the comparison of (a', c') in cartouche (7b) can be followed immediately with an application process at (7c) to predict d', which is then compared with d' at (9c), and, unless "justification" is required at (9d), this comparison is followed by the report of the evaluation at box (10). (This possibility was suggested independently by Pellegrino and Lyon [1979, p. 178] in their review of Sternberg's monograph.)

Sternberg's own analysis is represented as route (2), shown in broken lines. In

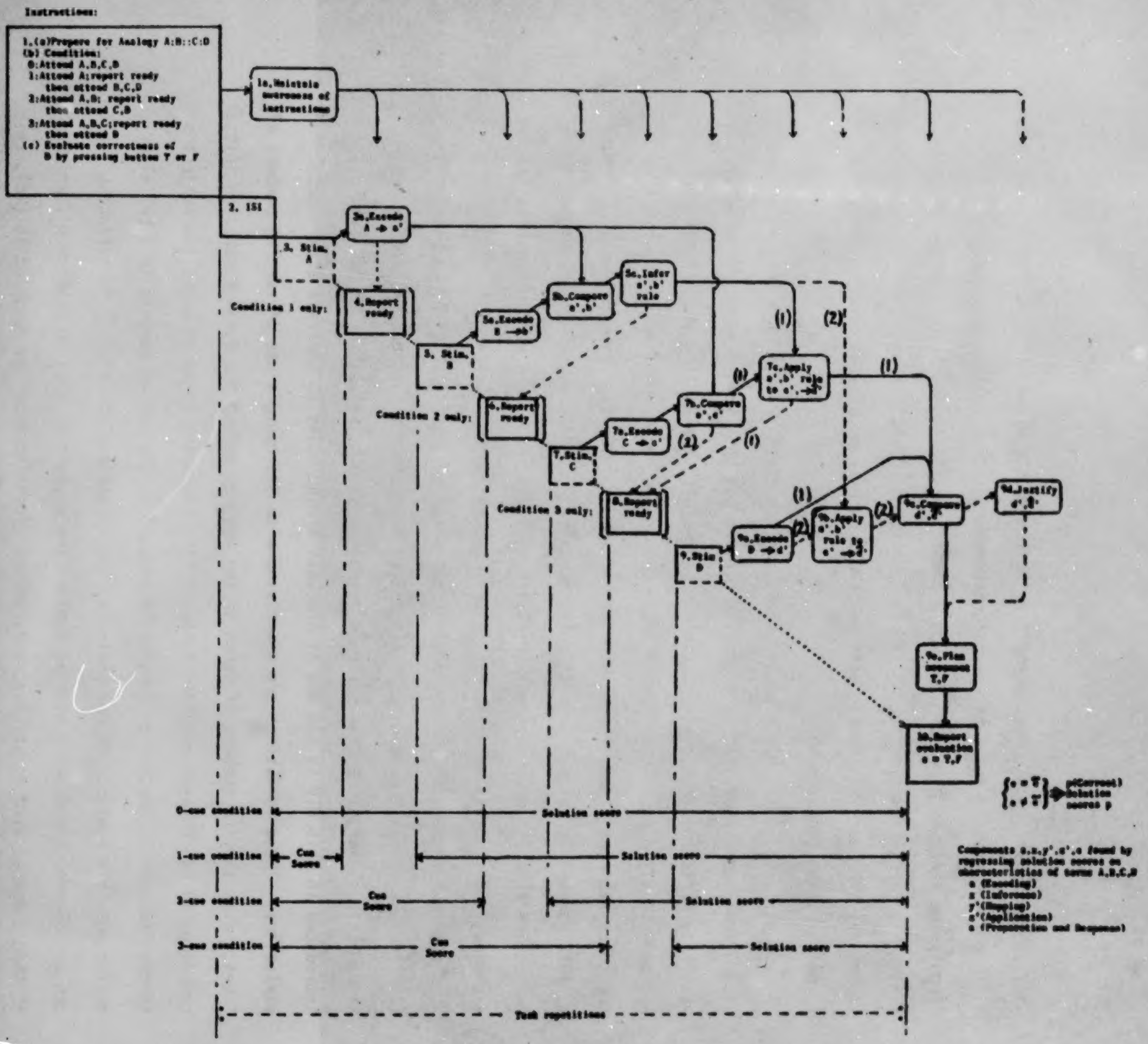
Instructions:
1.(a)Prepare for Analogy A:B::C:D
(b) Condition:
0:Attend A,B,C,D
1:Attend A;report ready then attend B,C,D
2:Attend A,B; report ready then attend C,D
3:Attend A,B,C;report ready then attend D
(c) Evaluate correctness of D by pressing button T or F
1a.Maintain awareness of instructions
2. ISI
3. Stim. A
3a.Encode A → a'
Condition 1 only:
4.Report ready
5. Stim. B
5a.Encode B → b'
5b.Compare a',b'
5c.Infer a',b' rule
(1)
(2)
Condition 2 only:
6.Report ready
7.Stim. C
7a.Encode C → c'
7b.Compare a',c'
7c.Apply a',b' rule to c',→d̂'
(1)
(2)
Condition 3 only:
8.Report ready
9.Stim D
9a.Encode D → d'
9b.Apply a',b' rule to c' → d̂'
9c.Compare d',d̂'
9d.Justify d',d̂'
9e.Plan response T,F
10.Report evaluation e = T,F
0-cue condition
Solution score
1-cue condition
Cue Score
Solution score
2-cue condition
Cue Score
Solution score
3-cue condition
Cue Score
Solution score
Task repetitions
e = T
e ≠ T
p(Correct) Solution scores p
Components a,x,y',z',c found by regressing solution scores on characteristics of terms A,B,C,D
a (Encoding)
x (Inference)
y'(Mapping)
z'(Application)
c (Preparation and Response)

FIGURE 3

that analysis, the "application" operation does not occur until (9b), i.e., after Stimulus D is presented. Essentially, the two routes represent different strategies that might be adopted by subjects. It would be too much of a diversion, at this point, to discuss how one might determine which strategy is used by a subject, or how one might attempt to impose one or the other strategy on a subject. In any case, it appears that the cue and solution scores under the 3-cue condition can be ambiguous as to whether account is taken of the two alternative strategies that may be adopted.

Another problem that appears in this analysis is the nature of the comparison process at (7b). Sternberg calls this comparison "mapping"; according to him it involves a test of whether c' is "in the range of" a'. (For example, if the analogy is RED:STOP::GREEN:GO, "green" is seen to be "in the range of" red, while foot, for example, would not be.) In Sternberg's experiments, c' is normally in the range of a', and therefore the comparison process at (7b) is in a sense trivial. It would be possible to vary the experiment, making this comparison non-trivial, by introducing "C" stimuli that are not in the range of the "A" stimuli and asking subjects to evaluate whether they are or are not in the range of "A."

It is hoped that the three DTR charts shown here will serve to give an impression of the usefulness of the technique for specifying and analyzing the characteristics of an ECT, or of the paradigm from which it is derived. The objective events (instructions, stimuli, responses), shown along the central diagonal time axis, contain the essential specification of the ECT. The specification and arrangement of cognitive processes in DTR charts may appear to be, and probably are, somewhat speculative. Whether or not this is critical in the identification of an ECT or a cognitive paradigm is not yet clear. It can be pointed out, however, that ECTs and cognitive paradigms are generally designed to disclose the operation of such cognitive processes, and those shown in the DTR charts of Figures 1-3 are among those postulated and tested for validity by researchers who have studied the corresponding paradigms. Further, with the progress of research with such paradigms there is now not only a substantial body of evidence for the operation of these cognitive processes but also a considerable amount of knowledge about their characteristics and the conditions under which they operate. For example, there is much evidence to the effect that people "encode" stimuli memorially, and information is available about the amount of time it takes to encode different types of stimuli. The body of knowledge concerning this and other cognitive processes has been drawn on in developing the DTR charts that have been shown here. It is beyond the scope of this survey to present this evidence in detail; various books, articles, and treatises on cognitive psychology may be consulted for this (Blumenthal, 1977; Estes, 1975-1978; Glass, Holyoak, & Santa, 1979; Lachman, Lachman, & Butterfield, 1979; Posner, 1973, 1978; Reynolds & Flagg, 1977; Wickelgren, 1979). Nevertheless, this background must be assumed to inform our survey of IDs in ECTs, since to a large extent the IDs are found to reside in the parameters of cognitive processes measured through experimental manipulation of cognitive paradigms.

Classification of the Paradigms of Cognitive Psychology

A further step in organizing the material that will be looked at in our survey of IDs in cognitive processes can be taken with an attempt to reduce the many paradigms of cognitive psychology to a small number of basic patterns. Through the construction and analysis of DTRs for a fair-sized sample of tasks that have yielded evidence for IDs, we believe that a useful classification, about to be set forth, has been achieved. It cannot be claimed that it is adequate for categorizing all cognitive tasks, for as yet no attempt has been made to apply it universally. Further, we dare not hope for general acceptance of the classification as it stands, for other cognitive psychologists will doubtless want to draw distinctions that we do not make, or will wish to coalesce or combine categories which we do not feel should be combined.

It would take much space and effort to explain the considerations that have led to the classification to be presented here. The classification will have to speak for itself, but at least we will try to explicate each category as thoroughly as possible. It should be understood that each paradigm category can cover a large, possibly indefinite number of ECTs, by changing (manipulating) values of the variables and parameters having to do with instructions, durations, temporal relations, number and types of stimuli, response modes, etc.

Thus far, eight basic paradigms have been distinguished, identified and described below in deliberately very general terms.

1. The perceptual apprehension paradigm

Basic purpose: To determine the minimal or threshold values of stimulus characteristics (usually, duration and/or intensity) required for an individual to apprehend a stimulus or its identity.

Basic structure: S is instructed to make some kind of report of a stimulus: his mere awareness of it, his identification of it, or its name. The stimulus is presented over a series of discrete trials, stimulus characteristics such as duration and/or intensity being varied over a range of values such as to yield different values of the probability that the individual will make a stimulus report that meets a specified standard or criterion. This probability is then determined as a function of the values of stimulus characteristics. Criterion levels of these variables are established by noting what values (or combinations thereof) yield a probability that is equal to a set level (e.g., 0.5; 0.95; 1.00). (If only one stimulus is involved, values of stimulus characteristics are initially set low and gradually increased over the trials, to minimize memory and priming effects.)

Possible experimental variations: Different types of stimuli: visual (light flashes, dots, non-symbolic patterns, colors, pictures, graphemes, printed words), auditory (clicks, tones, phonemes or syllables, spoken words). Different conditions: giving Ss different amounts of foreknowledge of stimuli (identity of stimulus class, stimulus set size), either by instruction or by pre-cuing (priming); insertion of interfering stimuli (masks introduced after stimulus presentation for a given duration). Different kinds of reports required: awareness, identification, naming, reading (in the case of printed words).

2. The reaction time and movement paradigm

Basic purpose: To determine the latency of a response to a stimulus (i.e., time from onset of stimulus to onset of response), given conditions in the stimulus (stimulus class, set size, stimulus intensity, etc.) and/or characteristics of the response, the response being only any movement that is contingent on the onset of the stimulus. (That is, this paradigm does not include ECTs that require retrieval of a specific response, such as a word, from memory; for such ECTs, see Paradigm 5.)

Basic structure: The subject being alert to the imminent onset of a stimulus, a stimulus is presented, usually for an indefinite duration, and in any event with duration/intensity characteristics such that the probability of response, Paradigm 1, is close to unity. The subject is instructed to make a specified response, nearly always some kind of movement (button pressing, vocalization), as rapidly as possible. Response latency is measured from onset of the stimulus to execution of the movement (usually to its onset, but sometimes to its completion).

Possible experimental variations: Different types of stimuli (as in Paradigm 1). Different arrangements concerning warning signals and other manipulations of S's alertness to the imminence of the stimulus. Different numbers of possible stimuli and associated reactions: "simple reaction time" is for one stimulus and one associated movement, while "choice reaction time" is for $m > 1$ distinguishable stimuli, each with a different associated reaction. Different arrangements concerning the time measurement of the response: either to onset of any movement (measuring "decision time") or to onset of a completion of a movement (measuring total reaction time including movement time). (In most cases it would be desirable to measure decision time and movement time separately. In some cases the interest may be in the movement time as a function of the requirements of that movement, in which case decision time and movement time must be measured separately.)

3. The evaluation/decision paradigm

Basic purpose: To determine the latency, appropriateness, and other characteristics of a judgment, evaluation, or decision, usually of a binary or quantitative character, about a stimulus (considered as a totality), usually as a function of the characteristics of the stimulus and/or the basis of the judgment.

Basic structure: The subject is pre-informed as to the class of stimuli to be presented and the basis on which a judgment is to be made. When the subject is made alert to the imminent presentation of the stimulus, the stimulus is presented and the judgment is rendered or reported. Time from stimulus onset to the rendering of the judgment is measured. (See Paradigm 2 concerning the desirability of distinguishing between decision time and any movement time.) Correctness, or other aspects of the adequacy of the judgment may also be noted.

Possible experimental variations: Different classes and characteristics of stimuli (as before, but also including fairly complex stimuli such as sentences). Different bases for judgment: familiarity, truth/falsity in terms of world-knowledge, sense/nonsense, presence/nonpresence in a particular class of stimuli (such as the lexicon of the English language). Different types of judgment: binary; quantitative comparison with a standard; "rating" on a scale.

4. The stimulus matching/comparison paradigm

Basic purpose: To determine the latency, appropriateness, and other characteristics of a (usually binary) decision as to the sameness, similarity, or correspondence of two stimuli with respect to specified attributes. If one (or both) of the stimuli has (have) been stored in memory beyond time for its iconic representation, the purpose may be to study the characteristics of the memory trace for the stimulus (or stimuli), as a function of time from initial exposure and any intervening events.

Basic structure: The subject is pre-informed as to the stimulus classes represented by the two stimuli X and Y, and the basis on which they are to be judged for sameness, similarity, or correspondence. Operationally, the two stimuli, X and Y are presented either simultaneously or at two points of time separated by a time interval t. (Even with simultaneous presentation, however, it is not always possible to assume that the subject attends to the two stimuli simultaneously. For this reason, a general recommendation is that the two stimuli be presented successively, often with some sort of time or other measurement taken on the first stimulus, according to Paradigm 3, if only for a judgment as to readiness to continue.) Time from first onset of a pair of stimuli X and Y, or (preferably) from onset of the second stimulus Y, is measured to onset of the rendering of the judgment. (As before, it is recommended that decision time be measured separately from any movement time.) The correctness or other aspects of the adequacy of the response may also be observed.

Possible experimental variations: Different classes of stimuli; the two stimuli may be drawn from the same class or from two different classes. The interval t may be experimentally varied, or be indefinite (as in certain types of memory experiments). Either stimulus may be an isolate, or be embedded in a set or a complex visual figure; in the latter case there may be an element of visual search or scanning.

Special note: This paradigm corresponds to what are ordinarily viewed as a number of distinct paradigms. Clearly the "Posner task," along with its variants (e.g., comparing two words for being synonyms, homophones, or from the same conceptual category) is included here. It is not so clear that such paradigms as the "Sternberg task" (probed search of short-term memory), or the "Neisser" visual search task should be included here, but on careful examination they do appear to be, because of the essential same-difference or inclusion/exclusion judgments that are involved in them. This paradigm may be considered as a special case or extension of Paradigm 3, in that a judgment is made (in accordance with Paradigm 3) about stimulus Y with respect to similarity to stimulus X.

5. The naming/reading/association paradigm

Basic purpose: To determine the latency, appropriateness, and other characteristics of the response the subject makes when, given a stimulus X, the subject is asked to produce a response Y that bears some predesignated type of relation or association with X that has been acquired and stored in the long-term "semantic memory" of the subjects (rather than in a contrived learning situation that took place in the relatively immediate past).

Basic structure: The subject is pre-informed as to the nature of the stimulus classes involved, and the type of relation or association that is prescribed to be characteristic of the response. On presentation of the stimulus, the subject is to make the response(s) as rapidly as possible. The time-of-occurrence characteristics of the response(s) relative to the onset of the stimulus are measured; the correctness or other aspects of the response(s) may also be observed.

Possible experimental variations: Different classes of stimuli (as before). Different types of relations; e.g.:

Stimulus (X)	Response (Y)
Picture	Name in language Z
Printed word	Spoken word (i.e., the printed word is "read aloud")
Spoken word	Opposite (spoken)
Printed word	(Written or spoken) "first word that comes to mind"

Special note 1: This is the first of the paradigms described so far in which the subject is required to produce a response other than a single movement (except insofar as Paradigm 1 may be extended to require the subject to name the stimulus when he apprehends it, in which case it becomes a combination of Paradigms 1 and 5). Generally, it is considered that this response is produced by some sort of retrieval process from long-term memory.

Special note 2: Tentatively, this paradigm is distinguished from Paradigm 6, Episodic Memory Read-Out (see below), on the supposition that "semantic memories" may be fundamentally different from episodic memories. Eventually evidence may suggest that the two paradigms be coalesced.

6. The episodic memory read-out paradigm

Basic purpose: To determine the latency, accuracy, or other characteristics of the response that a subject makes when, given a stimulus X, the subject is asked to produce a response Y that bears some predesignated type of relation or association with stimulus X that has been acquired in the relatively recent past, over the period t with or without contrived intervening events.

Basic structure: The task involves two phases, a learning or acquisition phase and a memory read-out phase. Learning of stimulus X (which may be complex) and associated Y (which may be merely an "imitative" rendition of X) may occur in any number of ways (according to "subparadigms" of learning, such as paired-associate learning by repeated trials, "study-test," etc.). In the memory read-out phase, the subject is required to produce Y either with or without cues, and with different possible constraints. Latency, accuracy, and other characteristics of responses are observed.

Possible experimental variations: When Y is an "imitative" rendition of X, the paradigm includes memory span, serial recall, free recall, and "Brown-Peterson" tasks; when $Y \neq X$, the paradigm includes the paired-associate task. X and Y may be drawn from the same or from different stimulus classes, and may be of varying set sizes. Temporal distance between the learning phase and the memory phase may be varied, and the presence/absence and characteristics of intervening and "interfering" events may also be varied.

7. The analogical reasoning paradigm

Basic purpose: To determine the latency, appropriateness, and other characteristics of responses made at various stages of tasks in which the stimuli are one or more terms from an analogy of the form A : B :: C : D. It is assumed that the cognitive processes required to make appropriate responses differ as a function of what subset of terms from the analogy have been presented up to a given time; the purpose of the paradigm includes that of attempting to isolate and differentiate these processes.

Basic structure: The subject is assumed to be pre-informed as to the nature of an analogy and the criteria for evaluating its correctness: An analogy is a true analogy if indeed term D is related to term C in the same way as term B is related to A. For a given experiment, the subject is informed as to the structure of the task, i.e., what subsets of terms are to be presented in different phases of the task and in what ways they are to be responded to. The task itself consists of the presentation of one or more terms of the analogy, either in a single exposure (in which case at least three terms would be presented) or in successive phases. Responses expected in each phase may range from a simple indication of readiness to continue to a further phase, to indications of the correctness of the complete set of terms as an analogy or to predictions of what term or terms would form a correct analogy. The latency, correctness, or other characteristics of these responses are observed or measured.

Possible experimental variations: Different classes and characteristics of stimuli (as before): pictorial representations, symbols, words, figural designs, mathematical expressions, etc. Different types of relations between the A and B terms (and correspondingly, the C and D terms). Different task structures, e.g. presentation of all four terms at once, vs. presentation in two or more sequential phases. (Figure 3 is a DTR chart for R. Sternberg's [1977] realization of this paradigm, typically in two phases.) Different types of responses expected, e.g. evaluation of correctness of a given term (given three others), choice of the correct term among two or more alternatives, or production of a fourth term, given three others.

Special note: In some respects this paradigm represents an aggregation of several other paradigms, and for this reason it may not be logically parallel with the others presented here. For example, a phase in which only terms A and B are presented would have features in common with Paradigms 3 and 4, in that a decision about these stimuli, or a certain type of comparison of them, is made. If a subject is required to predict one term, given a knowledge of the other three, the paradigm has characteristics similar to those of Paradigm 5 in which a readout of semantic memory is involved. Nevertheless, this paradigm seems to involve certain special cognitive processes, for example, rule application, that are not called for in the other paradigms; therefore, it is identified here as distinct from the others.

8. The algorithmic manipulation paradigm

Basic purpose: To determine the speed, correctness, and other characteristics of responses when subjects are presented with a problem requiring the application of one or more algorithms involving semantic, logical, or quantitative relationships. The algorithms may include ones previously learned and stored in memory (e.g., arithmetic facts and procedures for adding numbers) or ones that are specific to the experiment and described in instructions or otherwise taught to the subjects before the task is performed.

Basic structure: The subject is pre-informed as to the nature of the task--the types of stimuli involved, the operations to be performed on them, the types of responses expected, and the like. On a ready signal, one or more stimuli are presented; the subject has to perform the required operations on them according to the prescribed algorithms or rules, and report his response. Speed and correctness of response are observed.

Possible experimental variations: Variations depend largely on the fact that there is a large variety of possible stimuli and algorithms to be performed on them. The task may be conducted in a single phase, or in multiple phases, each requiring a response.

Special note: As in the case of Paradigm 7, this paradigm may contain features of other paradigms. Nevertheless, the focus on the application of algorithms makes this paradigm somewhat distinct from the others.

Cognitive Processes Assumed in the Paradigms

The paradigms described above have been designed to study the operation of a number of assumed cognitive processes. Before we undertake to describe how the paradigms can be used in this way, it is necessary to identify and define these assumed cognitive processes. It should be one of the goals of cognitive psychology to define a small finite set of distinct cognitive processes that could be used to account for all cognitive activity, including not only simple tasks like choice reaction, comparison of stimuli, and object naming, but also language production and comprehension, reasoning, decision-making, problem solving, and so forth. This is an ambitious goal that cannot be undertaken here seriously, but we propose a set of 10 distinct processes that are believed to be potentially useful in analyzing the paradigms and ECTs that will be examined in our survey of the literature of IDs in cognitive tasks. In theory, they might also be used in accounting in great detail for higher-level tasks such as language production and comprehension, but insofar as such processes play a role in the ECTs that are studied here, we do not attempt to make this refined analysis, using the proposed processes only to designate molar assemblages of related processes. For example, one of the proposed processes is Encoding, the formation of a mental representation of a stimulus. One can say that the meaning or propositional content of a sentence is encoded, without specifying the manner in which this encoding occurs, or the manner in which the individual phonemes, syllables, words, and higher-level constituents of a sentence are processed. Actually, the overall "encoding" of a sentence probably involves a rather complex set of processes, not all of which would be instances of the elementary encoding process defined below. Thus, our formalization goes only to the level of detail and analysis deemed necessary to isolate distinct processes in the cognitive paradigms and ECTs that are examined in this monograph. In some instances, the approach is fairly molecular; in others, it remains clearly molar. This is true despite the fact that our analysis of ECTs may appear to be extremely detailed and "molecular." As will be seen, it frequently requires 20 or more separate process-steps to describe a subject's presumed cognitive performance in even a very simple cognitive task such as making a choice reaction or comparing two stimuli.

Because the level of detail that seems to be required leads to a considerable complexity and volume of data, computer simulation methods have been resorted to in order to deal with this. Partly for this reason, and partly for the sake of achieving rigor, each postulated process has been given a formal characterization in terms of arguments (in the mathematical sense of the term). In this formalization, the four arguments for each process have a fixed order. For uniformity, the first argument is always the outcome, terminal state, or result of the process. The second and third arguments are the operands or contents operated on. Some processes involve only one operand, and in these cases the third argument is considered null. The fourth argument is the rule, condition, or other basis by which the process is governed. These notions will become clearer when the details for each process are presented.

Also, each process has been assigned a 6-character, reasonably pronounceable mnemonic to serve as the name of a routine or subroutine in the computer program, SIMCOG, that has been developed (though incompletely) to facilitate the analysis of ECTs. In many cases 4-character mnemonics have been devised for the arguments of a process; these arguments are actually names of variables.

It is envisaged that a large amount of research literature could be assembled concerning each one of the proposed processes. This literature would be found to deal with the effects, upon the terminal state of a process and the speed and efficiency of its operation, of different types of operands, rules, and conditions, and it would presumably be possible to describe any given experimental task in terms of the set of cognitive processes postulated here. It will be noticed that although the list of processes given here was developed independently on the basis of an analysis of a sample of ECTs, the list exhibits considerable resemblance to that proposed by Newell and Simon (1972).

In the development of this list, little has been assumed about the "architecture" of the cognitive system (Hunt, Frost, & Lunneborg, 1973, p. 96). That is, an excessive "boxology" (M. Eysenck, 1977, p. 6) has been avoided. It is assumed only that the cognitive processes take place somewhere in the higher neural system, often on the basis of stimuli that somehow become entered into that system from the external or the bodily environment, but also on the basis of the outcomes of other cognitive processes occurring in that system. Some of the cognitive processes (particularly MONITR and ATSTIM) seem to have primarily "executive" functions, but there is no implication that there is actually an "executive" that controls all cognitive processing. Likewise, some of the processes seem to refer to memory functions. Whether these memory functions are in "short-term memory," or in some "longer"-term memory, is regarded as not of great interest or import. Differentiation of memories of different "terms" would be a function of analysis of temporal and other parameters of processes. The short- or long-term status of memories is assumed to be a matter of degree rather than kind.

1. The Monitor process: MONITR (SPLN, INST, ---, ARB)

where SPLN = the subject's perceived "plan" of the task as received from oral or written instructions;

INST = the task instructions that are presented (by whatever means) to the subject in advance of his being administered a specific task;

ARB = a symbol representing the general conditions of an experiment, including, for example, the fact that a subject's attendance at an experiment is based on some "arbitrary" convention in which the instructions may have less force than, say, a military command.

Discussion: Every one of the cognitive paradigms described here requires that the experimental subject be instructed as to the nature of the task and what kinds of responses are expected. As implied earlier in the discussion of what makes a task "cognitive," it can be said that the paradigms (and their associated ECTs) are "cognitive" to the extent that (a) they assume that the experimental subject is given specific information as to the nature of the task and the task goals and requirements and (b) different experimental results--often drastically different--can be obtained under different task instructions, even if the experimental conditions (stimuli, sequence and timing of stimuli, means of response, etc.) remain objectively precisely the same. Examples of this are manifold. A simple case would be the visual presentation of a single printed word; obviously, the subject's response, its speed or latency, and possibly its "correctness," will vary as a function of whether the subject is asked to read the word aloud, to give its opposite (if it has one), to think of an associated word, to judge whether it refers to an instance of a given superordinate category, to judge its familiarity or frequency, or whatnot. The same phenomenon holds in more complex tasks, although typically complexity leads to more constraint in such tasks.

The Monitor process (MONITR) is our general name for the set of instructions, rules, and guidelines that the subject maintains (presumably in memory) throughout the performance of a task. It corresponds to the "production system" postulated by Newell (1973) to describe the sequence of mental operations in computer terms. The Monitor process may be analyzed into smaller, component processes including those described below, but for purposes of clarity, exposition, and task analysis it seems wise to retain the concept of a single process or "program" that the experimental subject is caused to "have in mind" as the subject responds in any particular experimental task setting.

Some aspects of the Monitor process are the following:

(1) Usually, the process has a hierarchical structure in the sense that it has one or a very small number of major goals, each of these having one or a small number of minor goals or "subgoals," each of these subgoals in turn possibly having still smaller subgoals, and so on down to the smallest component that can be identified. (See Bower [1975, pp. 29-33] for an exposition of this concept and a reference to the fact that it was first emphasized in cognitive psychology by Miller, Galanter, and Pribram [1960] in their book Plans and the Structure of Behavior.)

(2) The process may also have non-hierarchical aspects in the sense that each major component, and possibly subcomponents, consists of a strict sequence of events or alternative events such as could be described by a computer flow diagram. A subject can be expected to form some mental representation of this sequencing of events, including the

conditions under which sequencing is affected by decisions or special conditions at various points.

(3) The subject's mental representation of both the hierarchical and non-hierarchical aspects of the task structure can be acquired either by being given oral or written instructions, by being given practice trials, or by some combination of verbal instructions and practice. (Practice may, of course, have other effects besides that of imparting a mental representation of the task. It may for example alter the way in which a subject responds to stimuli.)

(4) Although verbal instruction and/or practice may be effective in imparting to the subject the higher-order aspects of the task and its components, instructions cannot be completely explicit about all subcomponents of the task. The Monitor process can therefore differ over subjects. Through predisposition, discovery, or otherwise, some subjects may arrive at particular task strategies that differ from those of other subjects. The Monitor process cannot be assumed to be the same for all subjects, and every effort needs to be made to identify the particular strategies employed by different subjects.

(5) A subject's mental representation of a task structure consists of a series of expectations as to what will or can happen, and in which order events will or can take place as the task procedure is followed through. This can be inferred from the fact that any deviations of actual events from these expectations (through "catch trials," for example) may cause perturbations in the subject's behavior. Expectations can also be formed with respect to such aspects of an experiment as the size of the stimulus set, the probabilities of different types of stimuli, the experimenters' preferences for different types of responses, and the like, although in many cases it may be difficult for an experimenter to detect or assess such expectations.

Undoubtedly there are individual differences in the ability to acquire and maintain a Monitor process that is efficient and appropriately adapted to the requirements of a particular experimental task. For example, R. Sternberg (1977) finds that the "Preparation-Response" parameter in his analogical reasoning task is a major source of individual differences; we take this parameter to represent the subject's degree of ability to maintain an appropriate process for monitoring his responses in the course of solving analytical reasoning tasks.

We have already mentioned (p. 19) the possibility of differences in subject strategies in the Sternberg analogical reasoning task, having to do with whether in the three-cue condition the subject tries to "predict" the fourth term of the analogy before it is actually presented. Another striking example of differences in subjects' monitoring processes comes in Hunt's (1978) report that in a Clark and Chase (1972) sentence verification task, results vary as a function of whether subjects choose to form a mental representation of a sentence's picture reference before or after the "picture" (a "star" and a "cross" in a vertical arrangement) is presented. In our terms, the two types of subjects have two monitoring processes that are distinct in at least some respects.

In formalizing the Monitor process for computer simulation work, we find it convenient to assume that the first argument of the process is SPLN, a sequence of processes selected from those that are described below. In the computer simulation work described later, these arguments are represented, therefore, in a data structure called SP (Subject's Plan); the MONITR process itself is always the first process entered in SP.

2. The Attention process: ATSTIM (Source, ESTM, ---, ---)

where Source = the point or region in the subject's sensory or imaginal space to which attention is directed, and from which the subject expects that a stimulus in some class of stimuli will be presented;

ESTM = a mental representation of the class of stimuli expected.

Discussion: The ATSTIM process (its name formed from attend stimulus) is a specific cognitive process that occurs at one or more points in all or nearly all experimental tasks. (In fact, it is difficult to imagine an experimental task that does not involve it in some way.) It is a process whereby the subject's conscious, focal attention is caused to be directed toward some potential stimulus source, with an expectation of, and concentration on the potential nature of, the stimulus to be presented. (On focal attention, see Blumenthal, 1977, pp. 13-21.) This can be done in any of several modalities, both those referring to different kinds of external stimuli (visual, auditory, tactile, etc.) and those referring to iconic memory stores, as in Sperling's (1960) iconic memory task, where a differential signal directs the subject to read out either the top or the bottom row of stimuli formed in a visual memory buffer. In the case of visual stimuli, the attentional process has the subject's gaze directed to a particular point or region of the visual field, as to a fixation point in a tachistoscopic presentation. In the auditory modality, the attentional process appears to represent "tuning" conscious attention to a particular type or range of potential stimuli (e.g., high tones, as opposed to low tones and noises), or to stimuli received in one ear as opposed to the other.

There is evidence that the degree of attention that can be maintained by a subject can vary. Certainly it can vary over long periods, as the large literature on vigilance suggests (Mackworth, 1969), but it can also vary over short periods, as is demonstrated by the literature on simple reaction time, where latencies can vary as a function of relatively minor variations in the temporal relation between alerting signals and the onset of the stimulus to be responded to. In simple reaction time experiments, it is necessary to vary this relation in some random fashion in order to avoid having the subject form a consistent expectation of when the stimulus will occur, with a consequent bias in the observed reaction time, but it would appear that there is no agreed-on standard time range over which the interval should vary. Keating and Bobbitt (1978), for example, varied their interval over 4, 6, and 8 seconds, whereas Rose (1974) varied the interval over .75 to 1.50 seconds. The consequences of such variation for the measurement of reaction time, or for measurement of IDs in reaction time, are not known. Any such consequences may reflect variation in attentional processes.

Experimental procedures for controlling S's attention range between those in which the experimenter assumes full responsibility, as it were, by himself controlling the timing of stimulus presentation, and those in which the timing is largely controlled by the subject--as in a "self-paced" experiment in which the subject is asked to report when he is "ready" for a particular phase of an experimental task, or actually to activate the onset of a stimulus by pressing a response button. Full experimental control has the advantage of enabling the study of certain memory effects that take place over time, but it has the disadvantage of allowing subject attention to vary. Unless there is specific reason for full experimenter control of stimulus timing, self-pacing by the subject seems to have some advantage in controlling degree of attention.

Many experimental settings require the subject to attend to a fairly large visual field (rather than a specific fixation point). This can be true if the subject is presented with pictures subtending large visual angles, or if the several stimulus locations in a choice reaction experiment are fairly distant from one another. In such cases the effect of the size of the visual field on experimental results deserves consideration; it is possible that IDs can arise from differences in Ss' ability to attend to large visual fields, or variations in their disposition to attend to different parts of such fields. In the case of sentences, paragraphs, or other printed verbal information, one relies partly on highly learned habits of left-to-right, top-to-bottom gaze to control the attentional process, but the large literature on eye movements (Just & Carpenter, 1976) suggests that these habits are highly variable. Snow (1978) has experimented with using eye movement observations to account for variations in Ss' performance on various types of mental test items.

During the attentional process, it may be assumed that the subject forms a mental representation of the expected stimulus. This representation is of a generalized, "fuzzy" character; it is often an expectation of a prototype rather than of any particular stimulus. For example, in a picture-naming experiment (under Paradigm 5) the subject would maintain a generalized representation of the stimulus class "picture"; if in the course of a picture-naming experiment, presentation of some stimulus (e.g., a geometric figure) that would not meet the expectations of the subject could easily cause a perturbation in the results, as opposed to those that might be obtained in an experiment in which the S's mental representation of the potential stimulus would include an otherwise deviant stimulus.

In our formal analysis and computer simulation work, the operand of ATSTIM is the subject's mental representation of the expected stimulus or of some generalized attribute of it. If there is more than one type of stimulus expected, or if one or more attributes are foci of attention, a separate ATSTIM process is assumed to exist for each stimulus or attribute, each having its own operand argument.

The available experimental literature on IDs in cognitive processes yields little evidence of IDs in attentional processes, at least in adults. A large literature on "selective attention" in children will not be considered here, but that literature mainly concerns what stimulus attributes children are likely to attend to.

3. The Apprehension process: APSTIM (ASTM, STIM, ---, ---)

where ASTM = the representation of the stimulus that occurs in a sensory buffer upon presentation of the stimulus;

STIM = the stimulus itself.

Discussion: The Apprehension process (its name APSTIM being formed from apprehend stimulus) is assumed to be simply what automatically occurs upon the presentation of a stimulus and the entrance of the stimulus energy into a sensory buffer to the extent that the subject is consciously aware of the stimulus and can compare it with ESTM, the representation of the expected stimulus. Normally the apprehension process is automatically followed by three other processes, yet to be described in detail:

TSTSIM: ASTM is compared to ESTM, in memory as the first argument of ATSTIM; if the comparison is successful (i.e., the actual stimulus is perceived to be in the class specified by ESTM), processing flows to the next normal process, CLOZR (perceptual integration); if not, particularly if the first argument of ATSTIM, ESTM, is null (in which case there may be a "surprise" reaction), information processing flows to processes that handle and report the lack of success in the comparison.

CLOZR: The information in the sensory buffer is subjected to a process whereby it is referred to a store of previous memories and integrated, perceptually, to a point where it can be recognized or identified as representing some percept or class of percepts. This process may fail or be incomplete, but if it succeeds, it is followed by the next normal process, REPFRM.

REPFRM: A representation of the stimulus is formed in memory (often called "working memory"), available for further processing. (For example, it may be again compared with a representation of the expected stimulus, by means of another TSTSIM operation. Or it may be "rehearsed," by the XECUTR process, and become strengthened in such a way as to persist much longer than it would otherwise.)

The apprehension process itself is successful only if the stimulus has enough energy to enter the appropriate sensory buffer. The amount of energy necessary for this to happen is assumed to be solely a function of the intensity and duration of the stimulus, as described by Bloch's law (see Blumenthal, 1977, pp. 34-37). The success of the apprehension process, and the parameters affecting its success, can be assessed through Paradigm 1 described above, but only if the subject's report is limited to one of the presence or absence of a stimulus, as opposed to further reports such as recognition or naming.

We are not aware of literature having to do with individual difference parameters of the apprehension process as such. (See discussion of the CLOZR process below.)

4. The Perceptual Integration process: CLOZR (ISTM, ASTM, ---, ---)

where ISTM = an integrated representation of the stimulus;

ASTM = the representation of the apprehended stimulus (from APSTIM).

Discussion: When the stimulus has sufficient energy to produce successful apprehension (through APSTIM), its representation in the sensory buffer, ASTM, is assumed to be automatically referred to a store of previous memories (in "working" memory or wherever) in such a way as to find a match ("correct" or not) with a previously formed memory representation. Normally this match will be "correct" or veridical, but in case there is some ambiguity in the stimulus, it may not be. The speed and success of this match depends upon various characteristics of the stimulus--particularly its familiarity and its degree of clarity or sharpness (essentially, its signal to noise ratio), and also, of course, upon whether a suitable representation in fact exists in memory, or is readily accessible (if, indeed, memories can vary in their availability in such a context). As one aspect of the (largely automatic) process of referral to a store of previous memories, there is a process of perceptual integration or closure (this term being the basis for the mnemonic selected for the process) in which the identity of the stimulus takes shape. In terms of a millisecond time scale, this process can be relatively slow and gradual. Results obtained by Wingfield (1968) suggest that even when the stimuli are pictures of familiar objects, with names of high frequency, an exposure time of about 9 msec is necessary to make the perceptual integration process successful; however, this time is increased to around 95 msec if the stimulus is immediately succeeded by a visual mask. This implies that even without the visual masking the perceptual integration process does not succeed until a substantial number of milliseconds have elapsed after the termination of the stimulus itself, the representation being formed on the basis of a persisting iconic memory image produced by the stimulus. (Thresholds are slightly greater for pictures having unfamiliar, low-frequency names.)

In Wingfield's experiment, the visual duration thresholds (VDTs) with no post-stimulus masking may be taken to be parameters relating to the Apprehension process, whereas the thresholds for the masking condition are related to parameters for the Perceptual Integration process.

Results for visual word-recognition thresholds can be interpreted in a similar way. For "familiar" words, VDTs ascertained without masking are only about half those determined with pre- and post-stimulus masking, and length of word has no appreciable effect. For pseudowords, the thresholds without masking are comparable to those for familiar words, though length of word has some effect; thresholds with masking are much higher, and length of word has a drastic effect (Richards & Heller, 1976). These results square with the notion that VDTs without masking, being indicators of the minimum sensory energy necessary to activate perception, reflect mainly the apprehension process, while VDTs with masking reflect the time of a perceptual integration process. The perceptual integration process is mainly a function of the amount of information to be processed. If the information comes already in a "packaged" form, as it does in the case of familiar words, the size of stimulus has little effect, but stimulus size and visual angle can have an effect in the case of stimuli that are unfamiliar and that have to be perceived in an analytic manner (Purcell, Stanovich, & Spector, 1978).

In any case, it seems desirable to make a clear distinction between the Apprehension process and the Perceptual Integration process. The parameters affecting the apprehension process are assumed to be solely a function of stimulus energy (intensity and duration), whereas the parameters of the perceptual integration process refer to characteristics of the stimulus and the likelihood and facility of a match being attained by a representation in LTM. The perceptual integration process is also affected by such variables as stimulus mutilation (as in the so-called Street Gestalt Completion test [Street, 1931] or the Mutilated Words Test [Thurstone, 1944] and stimulus blurring [J. Frederiksen, 1967]). In the auditory modality, signal-noise ratio is a factor. It is also possible that results obtained in assessing perceptual integration are affected by the subject's response criterion in a signal-detection sense, in which case it might be desirable (though we have not done so) to formalize the S's response criterion as a third argument (as an operand) or fourth argument (as a rule or condition) of the CLOZR process.

As here formalized, CLOZR has only one operand, namely the representation of the apprehended stimulus, ASTM. In a sense, however, it has many more arguments, namely the large numbers of memory representations that may be involved in its integration, but using these arguments in a formal analysis would be inconvenient, to say the least.

Individual differences in the operation of the CLOZR process, we speculate, could arise in either of two ways: (a) There may be intrinsic IDs in the parameters of the process itself, i.e. speed and probability of success, independent of the particular stimulus contents operated on, and (b) IDs may arise in the subjects' overall familiarity and experience with the stimulus contents being operated on, and in the availability and accessibility of the LTM representations involved in retrieving a match to the argument of the CLOZR process. The latter types of IDs clearly appear, for example, in data on word-recognition thresholds (Richards & Platnick, 1974), but a later experiment by Platnick and Richards (1977) suggests that word-recognition thresholds may also be a function of the former type of IDs, in that the thresholds were significantly related to scores on a Speed of Closure factor. Nevertheless, this evidence is inconclusive because of the involvement of word stimuli in some of the Speed of Closure tests.

5. The Encoding process: REPFRM (REP, ISTM, ---, ---)

where REP = a representation formed in memory;

ISTM = a representation passed to it from some other cognitive process, such as CLOZR or FOCORP (described below).

Discussion: The Encoding process is that of forming a mental representation of a stimulus, or some derivate thereof such as an attribute or associated concept, in memory (initially, at least, in "working" memory or the memory of focal attention), for further processing. It is thought to occur automatically, and virtually timelessly, upon the successful completion of the CLOZR process. It can, however, be formed as the result of other cognitive processes. The "fate" or further status of the representation so formed ("rep" for short) will depend upon the size of the working memory buffer, the likelihood of its being passed to further, "longer-term" memories through rehearsal and other processes (Atkinson & Shiffrin, 1968), and the operation of interfering stimulus processes. According to some theories of memory the rep is subject to a decay function over time.

Depending on the experimental task (instructions, experimental conditions, etc.), the encoding process may extend to different parts of a memory network. Some authors (notably, Craik & Lockhart, 1975; Cermak & Craik, 1979) speak of this phenomenon in terms of "levels" of processing, implying that processing can be measured in terms of "depth." We believe that it is preferable to deal with this phenomenon without reference to "levels" or "depth," accounting for it rather in terms of different processes of attention (ATSTIM) and the formation of different or multiple reps on the basis of given instructions, attentional dispositions, and complex stimuli (i.e., stimuli with many attributes). One may observe, for example, that experiments on "levels of processing" almost uniformly control memory processing by the use of different instructions, inducing different attentional processes and thus different reps of expected stimuli and stimulus attributes.

This fact, incidentally, prompts the observation that we postulate that REPFRM is a process that can occur in response to instructions (for instructions are, after all, stimuli). The reps so formed are assumed to be maintained in some form throughout the course of an experimental task.

The formation of a rep is essentially what Posner and Rogers (1978, p. 148) had in mind in speaking of abstraction as "the recoding of information in a reduced or condensed form." That is, the rep formed from a stimulus seldom if ever contains all the information contained in the original stimulus. The rep that a subject forms from seeing a dog or a picture of a dog does not necessarily contain information on the length of the dog's ears, legs, and tail, or even, perhaps, the dog's breed or type. A rep, however, is not equivalent to Morton's (1970) logogen, which appears to be a representation stored in LTM and to have a primarily verbal character. A rep can presumably become a logogen, however, if it is stored in memory in such a way that it persists over long periods and is cast in verbal form.

Language comprehension can be thought of as involving the formation of reps, not only of the individual words and other constituents of an utterance or text, but of the propositional or other content of the utterance or text. This occurs, however, only through fairly complex processes in which reps of individual words are further processed through a language comprehension system. It is beyond the scope of the present treatment to give an account of language comprehension processing; we shall simply assume that it occurs (as it obviously does), and that there can be individual differences in the speed and success of such processing.

Much more could be said about the encoding process, and of course there is a large literature concerned with it (e.g., Melton & Martin, 1972; Glass, Holyoak, & Santa, 1979, Chapter 5).

6. The *Comparison* process: TSTSIM (OURP, REP1, REP2, BSIS)

where OURP = the outcome of a comparison of REP1 and REP2;

REP1, REP2 = the reps to be compared (usually, REP2 having a longer history in memory);

BSIS = the rule or basis controlling the comparison (e.g., absolute identity vs. mere similarity).

Discussion: TSTSIM (formed from "*test*ing *sim*ilarity") is that of comparing two reps for sameness or similarity.* Frequently, these are reps formed on the basis of two external stimulus presentations, but they can be formed as the result of other cognitive processes. TSTSIM thus has two operands, the reps that are compared. The process is conditioned by the argument designated BSIS, the basis governing the comparison. However, BSIS does *not* refer to the "respect" in which the reps are compared, but solely to the response criterion, i.e. the degree of constraint imposed--whether a positive outcome is to be arrived at only if the two reps are perceived as absolutely identical, or it can be positive if the reps are similar though not identical. BSIS can also take a value such that the subject is asked to report (as the output of the comparison) a judgment of the degree of similarity.

In a variety of experimental settings involving comparisons, the TSTSIM process can operate, but only after reps have been formed that can be the inputs to this process. For example, if one requires a comparison of two alphabetic characters on the basis of "name" sameness (e.g., uppercase *A* and lowercase *a*) or of similarity of classification as vowel or consonant letter (Posner & Mitchell, 1967; Rose & Fernandes, 1977), the stimuli involved must first be converted (typically, through the FICORP process described below) to representations of names or vowel/consonant classifications before they become operands of the TSTSIM process. Similarly, sentence-picture

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*Note that the term "comparison" used here refers *only* to comparison with respect to similarity. It does not refer to the process implied in the frequent use of the term to mean "finding in what respect(s) two items are different," or "finding which of two items is greater (or smaller) in magnitude on a specified dimension." Such processes are in the present context assumed to involve other processes besides TSTSIM.

comparisons required in the task studied by Clark and Chase (1972) involve conversion of sentences and pictures to comparable types of representations before those are entered in the TSTSIM process.

The types of outcomes of a TSTSIM operation depend on constraints imposed by the instructions, represented in the argument BSIS. In the simplest case, a binary decision ("yes"/"no" or "same"/"different") is made, the outcome being matched with a rep of "yes," "no," "same," or "different" from memory (by the process FICORP described below) for further processing through XECUTR (execution of response). In other cases, the outcome can consist of a judgment of degree of similarity, or a judgment of the amount of distance that separates the two stimuli on some dimension (e.g., musical pitch).

Although the clearest examples of the TSTSIM process are found in tasks that explicitly require the subject to make a comparison of similarity between the reps derived from two stimuli (e.g., in the Posner & Mitchell [1967] task), the process applies also to the comparison between reps formed in any way whatsoever, for example as a result of various other cognitive processes performed on stimuli or on reps derived from them. Consider, for example, how a subject can be assumed to perform an "AND-gate" operation such as that found in the variant of the Posner task studied by Kroll and Parks (1978). At one point in this task the subject has to decide whether both the left-hand and the right-hand stimuli (alphabetic characters) in two successive stimulus presentations are the "same" with respect to name identity. (E.g., for Ab on the "memory slide" and aB on the test slide, the comparison is positive, but for Ab and bb on the two slides the comparison would be negative.) This comparison might be performed in at least two ways. One is to form a new rep from the stimuli on the memory slide, consisting simply of the names of the stimuli in their presented order. This then would be tested against an analogous rep formed from the symbols on the test slide. (Thus, a rep from the memory slide, "ab," would be tested against a rep "ab" from the test slide.) Although this is probably the manner in which the task would usually be performed, another procedure involves an "AND-gate," i.e., the finding that both of the comparisons (the one on the left and the one on the right) give positive outcomes. Each of these tests has an outcome; call them 0_L and 0_R, and each such outcome has an attribute, either "S" or "D." The AND-gate comparison is then accomplished by considering whether these attributes are the same; i.e., for a positive finding, $0_L = S$ and $0_R = S$, therefore $S_L = S_R$. Subjects might be much more likely to use an AND-gate procedure of this type if the stimuli were instances of categories, such that the "memory slide" might have, say, horse - table, and the test slide cow - chair, such that it might be more difficult to form new representations of the form "animal" - "furniture." In any case, these examples are meant to illustrate how the comparison process can involve reps not formed directly from the stimuli but indirectly, through other reps formed from the stimuli.

Although the comparison process is often under the control of reps formed from instructions, it can also be assumed to be capable of operating automatically, independently of any explicit instructions regarding a comparison, whenever two reps are formed, through whatever process, that the subject may expect to be similar but that are usually different. For example, in one experimental variation of the task developed by Meyer, Schvaneveldt, and Ruddy (1974) and used by Rose and Fernandes (1977) in an information-processing assessment battery, the subject has to read aloud a word, such as MINT, followed immediately by another word, such as PINT, that is to be read aloud. The second word is graphemically similar but "phonetically different" from the first word. The resulting interference effect is possibly to be explained by an automatic, negative comparison of two reps, a phonetic one, /pint/, formed from the graphemic representation as cued by the preceding word MINT, and another phonetic one, /paynt/, formed from the word in its normal reading.

Similarly, the interference effect noted in the well-known Stroop (1938) task is possibly to be explained through an automatic, negative comparison of two reps--one from the color in which a word (e.g., GREEN printed in red) is printed, and one from the normal reading of the word presented.

At this writing it is not clear whether IDs arising in tasks and tests that involve TSTSIM stem from differences in performing the TSTSIM operation as such, or from differences in the availability and accessibility of the reps on which this process is performed.

7. The Co-Representation-Formation process: FOCORP (OURP, REP1, [REP2], BSIS)

where OURP = a co-representation that is formed in association with REP1 and (optionally) REP2;

REP1, REP2 = operands passed from other cognitive processes. (Some processes involve only REP1, while others also involve a second operand, REP2.)

BSIS = the rule or other basis governing the process.

Discussion: The Co-Representation-Formation process FOCORP (the name being formed from "form co-representation") is the process of establishing a new representation in memory in association with one with a longer history, or with two such reps, also associated with a rule BSIS that gives the basis on which the corepresentation is formed. Essentially this process is the foundation of any learning of new representations, such as the names for objects, arbitrary associations in "verbal learning" experiments, number facts, and the like. As examples we give:

FOCORP ("chaise", "chair", ---, French translation)
[the French word chaise is a translation of the English word chair]

FOCORP ("chaise", chair, ---, name in French)
[the word "chaise" is the name of an object chair in French]

FOCORP ("7", 49, ---, square root)
[7 is the square root of 49]

FOCORP (2, 7, 5, difference)
[2 is the result of subtracting 5 from 7]

FOCORP ("GEX", 49, ---, ARB)
["GEX" is an arbitrary association established with 49]

FOCORP ([5-7], 7, 5, SEQ)
["5-7" is established as part of a sequence in a memory span task]

Many paradigms of cognitive tasks, e.g. Paradigm 5, assume that FOCORPs have occurred in the previous history of the individual and are retained in memory so that they are more or less accessible for recall. In Paradigm 6, FOCORP processes occur in the learning or acquisition phase, to be drawn on or tested in the recall phase through FICORP processes (see below). The success of these latter processes must depend in part on the success with which FOCORP processes have occurred in the acquisition phase, as well as many other variables such as the time interval between the learning and the recall phases, activities that intervene in that interval, etc.,--in short with the many variables that have been dealt with in the large literature on various subparadigms of learning (memory span, serial recall, free recall, paired-associate learning, etc.). We will not attempt to deal with this literature here except insofar as it concerns IDs in memory functions.

8. The Co-Representation Retrieval process: FICORP (OURP, REP1, [REP2], BSIS)

where OURP = the co-representation found or retrieved for REP1 and (optionally) REP2, given BSIS;

REP1, REP2 = operands passed from other cognitive processes;

BSIS = the rule or other basis governing the process.

Discussion: The FICORP process (the name being formed from "find co--representation") is complementary to the FOCORP process, and the structure of its arguments is similar. A FICORP process cannot be successful unless an appropriate FOCORP process has occurred and the result has been stored in memory. Were we to give examples of FICORP processes, they would be similar to those given above for FOCORPs.

FICORP is a very general process that is found in all or nearly all cognitive tasks at one or more points. Possibly TSTSIM, the comparison process described above, should be formulated as a type of FICORP, in the formalism

FICORP ("outcome," A, B, compare for sameness).

For the present, however, we will treat TSTSIM as different from FICORP, since it does not seem to contain the element of search which we believe is characteristic of FICORP.

Indeed, the name we have assigned to this process emphasizes that it involves an element of search, that is, search for the "co-representation" or "co-rep" (for short) for a given rep or pair of reps, selected on some basis.

Cases of FICORP with one operand occur in a variety of simple cognitive tasks. In a choice reaction experiment, the rep of the response that is to be chosen must be found or retrieved, contingent on the value of the stimulus. The rule on which the retrieval is based may involve some arbitrary set of correspondences established in instructions, e.g. select "left hand" for "green," and "right hand" for "red" (as in the experiment conducted by Keating & Bobbitt, 1978), or select "position close to the stimulus light" (for a hand movement to that position) on the basis of "position of stimulus light" (as in the choice-reaction experiment reported by Jensen, 1979). FICORP may, on the other hand, involve a retrieval process based on a long-standing memory. For example, in an experiment on absolute pitch judgment conducted by the writer (Carroll, 1975), the subject was required to hit or "play" the piano note corresponding to a heard pitch. There could be two successive FICORPs in the case: First a rep of the identity of the note is retrieved from the heard pitch, and then a rep of the position of the note on the piano keyboard is retrieved from the rep of the identity of the note.

One-operand FICORP processes are an essential aspect of Paradigm 5, which requires the subject to name, read, or find an association for, some stimulus. In our terms, in response to the rep of the stimulus, an associated co-rep must be found--a rep of the corresponding name, reading, or association. The particular kind of co-rep to be found is specified by the fourth argument of the process (e.g., NAME, READING, ASSOCIATION, etc.).

Two-operand FICORPs are characteristically found in Paradigms 7 and 8. In the former, the analogical reasoning paradigm, a typical FICORP is that of inference: Given the A and B terms of the analogy, the subject must find a co-rep of the relation between them (e.g., given A = foot, B = shoe, the rep formed might be described as "article of clothing for a bodily limb"). In the latter, the algorithmic manipulation paradigm, a typical FICORP might be the adding or subtraction of two numbers, often done in a series of such FICORPs.

There can be both speed and accuracy aspects of the FICORP process. It takes a certain amount of time to complete, and it may be completed either successfully or unsuccessfully. Unsuccessful completion consists of not finding a co-rep, or finding a co-rep that is incorrect or inappropriate in terms of some objective, external standard.

Under what conditions does the FICORP process involve "search" of a store of co-reps? Hick (1952) found that in many experimental settings, the average choice reaction time increases linearly with the logarithm of the number of alternatives; the function (originally discovered by Merkel in 1885) has been verified so often that it is described as "Hick's law," though perhaps it should be dubbed "Merkel's law." Recent examples of experiments in which the data follow this law are those of Carroll (1975), for absolute pitch judgments (where as many as 64 alternative choices could be made), and Jensen (1979), who claimed that the slope of the function was negatively related to intelligence. The essential choices in both these experiments may be regarded as FICORP processes in which the correct choice relies on selecting from among $\underline{n}$ alternatives, or co-reps. It might be assumed that each co-rep would have been formed in memory by a FOCORP process. This is clearly the case in Carroll's experiment; it appears that people with absolute pitch ability possess a mental representation of each possible pitch in the musical scale (at least within the range of the piano keyboard) and are able quite rapidly to retrieve the identity of any given pitch and its position on the keyboard. The set-size effect was obtained by using different set sizes (1, 4, 16, 64) in different blocks of experimental trials. Jensen had set sizes of 1, 2, 4, 8 and also obtained a set-size effect. In his experiment, however, it is not necessary to assume that subjects had learned separate co-reps for each stimulus light. His subjects' task was simply to press a button next to the presented stimulus light and no prior learning of these positions was required. This suggests that the source of the set-size effect is not the number of co-reps previously learned but the number of expectations that are set up in an experiment. Possibly, therefore, the set-size effect can be interpreted as a function of the number of ESTMs (expected stimuli) formed in ATSTIM processes. This interpretation would cover Carroll's experiment as well as Jensen's and others like it (Hyman, 1953), and is also implied by Wickelgren's statement (1979, p. 181) that the set-size effect is associated with the width of the "attentional set." The set-size effect therefore seems not to be a function of retrieval processes, but of attentional processes (in our terms, ATSTIM processes). The set-size effect does not stem from a "search" of co-reps.

This does not exclude the possibility, however, that FICORP involves a search process when the reps or co-reps to be retrieved vary in availability, as in the picture naming task studied by Oldfield and Wingfield (1965), Carroll and White (1973a), and Lachman, Shaffer, and Hennrikus (1974). These studies show that speed of retrieval is a function of such variables as stimulus codability and name-word frequency and age-of-acquisition, and there are indications of consistent individual differences in retrieval rates (Carroll, 1976b). Also, various types of learning and memory experiments can involve FICORP processes (as well as FOCORP processes in the learning phases), and there are wide individual differences in performance on such tasks as free-recall, serial learning, and paired-associate learning that may reflect FICORP processes (Malmi, Underwood, & Carroll, 1979). In all tasks involving such processes, availability of reps can be modified by practice and priming effects, and can vary as a function of time lapse between learning and testing, and interference effects.

9. The Transformation process: TRAREP (OURP, REP1, [REP2], BSIS)

where OURP = a rep that has been transformed from REP1 and possibly REP2;
REP1, REP2 = operands passed from other cognitive processes;
BSIS = the basis of the transformation, generally an indicator of the type of transformation performed.

Discussion: This process (its name being formed from "transformation of representation") is that by which a given rep is transformed or changed on some specified basis. It could be formalized as a special case of FICORP, but it seems desirable to distinguish it from FICORP because in FICORP, the original operand (or operands) is (are) not necessarily changed, lost, or displaced, whereas in TRAREP it is assumed that the operand is actually changed or transformed, and thus lost, at least temporarily.

In the visual modality, several types of transformations can take place, such as change of imaginal size or location (Kosslyn, 1975) or change by mental rotation (Shepard & Metzler, 1971). In the auditory modality, a transformation could take the form of a change in pitch (as of a chord or a melody). Individual and group differences have been observed in the speed of mental rotation (Shepard & Feng, 1972; Tapley & Bryden, 1977).

10. The Response Execution process: XECUTR (OUMV, REP, ---, BSIS)

where OUMV = a covert or overt movement, including the cognitive planning of such a movement;

REP = an operand passed from another cognitive process which specifies the movement to be made;

BSIS = a specification of the type of movement (e.g., finger response button press, overt vocalization, covert vocalization, etc.).

Discussion: This process, whose mnemonic name is formed in an obvious way, is that of operating on a REP, that specifies a target response, in such a way as to plan and produce the actual response, OUMV. In most ECTs that have been studied, the final response, at least, is overt. Usually, movements of the hand or fingers, as in pressing response buttons, or verbal responses ("yes," "no," the spoken name of an object, reading aloud of a printed letter or word, etc.) are required, but other types of motor response could be employed (eyeblinks, foot movements, etc.). XECUTR is, however, thought of as a primarily cognitive process that involves planning the required movement, utterance, or what not. The process is mainly what precedes the overt response, from the point of time that other processes have formed an appropriate rep that specifies the target response. The actual response is generally an automatic outcome of that planning. Speed or latency measurements can usually be best made by observing the time the subject takes to begin a response, from some prior point in the task, rather than the time taken to complete it, because the latter can include some component of movement time (Fitts, 1954; Fitts & Peterson, 1964) or articulation time. This can be a serious problem when there is more than one button to press and when the subject's hand or finger has to leave some fixed (or worse still, arbitrary or random) position before going to a given response position. The problem can be largely eliminated by computing latency measurements up to the point of time at which the subject leaves some sort of "home position," rather than up to the time the target response button is pressed. If desired, the XECUTR process can then be observed in two stages, the first being a function of decision and movement planning time and the second a function of movement time. In the case of vocal responses, latency can be taken up to the point of initiating the vocalization, and if desired, the time of the actual vocalization can be separately observed.

The XECUTR process may also involve covert or "subvocal" responses, as in the case of covert "rehearsal" (when the subject "silently" or "mentally" repeats stimuli or responses). Rehearsal can either be called for in task instructions or be spontaneously initiated and performed by the subject. Although it may be difficult to measure the timing or latency of covert responses, the possible occurrence of covert responses must be provided for in the analysis of cognitive tasks.

Several examples of XECUTR processes may be presented in terms of its first two arguments, OUMV and REP. Just before the response in a simple reaction-time task, REP is the rep formed as a result of apprehension and perceptual integration of the stimulus, and OUMV is the planning and initiation of a response. In a choice-reaction task, REP is the rep formed as the outcome of one or more FICORP processes in which a rep (or co-rep) corresponding to the particular stimulus presented is found; OUMV is (or should be) the planning and initiation of the response. In a successive-presentation comparison task (Paradigm 4) REP is the result of a FICORP process in which the appropriate co-rep of the outcome of a TSTSIM process is found, and OUMV is as before the planning and initiation of the overt response. In a picture-naming or word-reading task (under Paradigm 5) REP is the rep of a word in memory, arrived at through a FICORP process, and OUMV is the planning and initiation of the vocalization of that word.

The actual time required by the XECUTR process is probably observable most clearly in simple reaction time tasks, because complications arising from the nature of the stimulus, the stimulus set size, the availability of the response, etc., can be controlled by using identical stimuli in all trials. Possibly Frederiksen's (1978) finding of an "Automaticity of Articulation" component of individual differences in certain reading tasks corresponds to an XECUTR process having to do with the vocalization of words.

Representation and Possible Simulation of ECTs by a Computer Program SIMCOG

Partly because of the level of detail that is involved in the analysis of cognitive tasks in terms of the 10 specific cognitive processes, and partly in the hope of eventually being able to simulate many aspects of experiments with such tasks, a computer program, SIMCOG, has been developed to represent ECTs. The program is written in very general terms so as, it is hoped, to permit the representation of any cognitive task at a useful level of detail and specificity.

The program is written in FORTRAN IV-PLUS for a PDP-11/45, but it could be translated into other computer languages. For the present exposition, it will suffice to describe the two main subroutines, EPLAN (the experimenter's plan) and SPLAN (the subject's plan). EPLAN can either call one of four types of actions that would be taken by an experimenter, or it can make a call to SPLAN, in effect passing program control to the subject and waiting for a subject response. The four types of actions that can be taken by the experimenter are:

CONSLT:	consult details of the experimental design in order to choose stimuli, change experimental conditions, etc.
PRESNT:	present something (e.g., instructions, stimuli, waiting periods, alerting signals, etc.)
NOTDTA:	note a response (e.g., latency, correctness, etc.)
QUIT:	terminate the experiment

SPLAN, when it has program control, can call, in any sequence desired, any of 10 subroutines corresponding to the 10 cognitive processes described in the previous section; it may also return control to EPLAN when operation of one or more of these subroutines has been partially or completely performed.

The sequence of EPLAN and SPLAN actions is controlled by data structures, EP and SP, respectively, that are specified in advance in any desired way, corresponding to any given ECT. These data structures are themselves essentially programs by which actions may be programmed to occur in any specified sequence under control of different conditions that may occur in the course of an experiment. That is, the data structures are programmed to cause the making of tests of conditions and the selection of alternative courses of action depending on the outcomes of those tests.

Each of the 10 cognitive process subroutines that may be called by SPLAN can contain information about how that process may be presumed to operate--information that could, for example, be drawn from the experimental literature, or specified in the form of testable hypotheses. Each of the process subroutines can set constants and parameters that remain in computer memory in such a way as potentially to affect the operation of other processes if they follow in a specified sequence.

The program also contains a simulated time clock that can be used to compute latencies and other information based on time.

Thus far, the usefulness of the SIMCOG program, which has been only partially developed, is seen primarily in the fact that it demands that its user be very explicit about the details of an ECT, in terms of both the experimenter's plan and the sequence of the cognitive processes postulated in the subject's "plan." For purposes of illustration, details of the EP and SP data structures and the resulting computer printouts for typical trials of certain ECTs are given in Figures 4, 5, 6, and 7. The first three of these figures correspond to the ECTs and DTRs displayed in Figures 1, 2, and 3, respectively, and thus illustrate the operation of SIMCOG for Paradigms 2 and 7. Figure 7 is for the VDT (visual duration threshold) and picture-naming latency data from an experiment by Wingfield (1968, Expt. I, pp. 227-230) and is intended to

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    EXPERIMENTER'S ACTIONS     SUBJECT'S  COGNITIVE PROCESSES AND RESPONSES
    ----------------------     -------------------------------------------

PRESENT INSTRUCTIONS(SPLAN)
 --GENERAL INSTRUCTIONS
                               (MONITR)--S SETS ARG1 FROM ARG2
                                         ON BASIS OF ARG4
                                    ARGS=SPLN,INST,NULL,ARG
                               (REPFRM)--S FORMS ARG1 IN MEM FROM ARG2
                                    ARGS=ELIT,INST,NULL,NULL
                               (FOCORP)--S FORMS ARG1=COREP FOR ARG2
                                         (& ARG3) ON BASIS OF ARG4
                                    ARGS=LEFT,GREN,NULL,CO R
                               (FOCORP)--S FORMS ARG1=COREP FOR ARG2
                                         (& ARG3) ON BASIS OF ARG4
                                    ARGS=RITE,RED ,NULL,COLR
                               (FOCORP)--S FORMS ARG1=COREP FOR ARG2
                                         (& ARG3) ON BASIS OF ARG4
                                    ARGS=LEFM,LEFT,NULL,POSN
                               (FOCORP)--S FORMS ARG1=COREP FOR ARG2
                                         (& ARG3) ON BASIS OF ARG4
                                    ARGS=RITM,RITE,NULL,POSN
                               (ATSTIM)--S ATTENDS ARG1 WITH ARG2
                                    ARGS=SRCE,ELIT,NULL,NULL
NOTE: NEXT TRIAL
SELECT RANDOM INTERVAL OVER  3 POSSIBILITY(=IES)
 FOR INTERTRIAL INTERVAL
SELECT STIMULUS # RANDOMLY FROM  2 POSSIBILITY(=IES)
 WITH REPLACEMENT(NO CONSTRAINT)

**************************************************************************
    EXPERIMENTER'S ACTIONS    SUBJECT'S COGNITIVE PROCESSES AND RESPONSES
    ----------------------    -------------------------------------------

EXP.VAR= 1, TOT.TRIAL #=  1, TRIAL # THIS BLOCK=  1
PRESENT TIME INTERVAL
 BETWEEN TRIALS
  DURATION= 4000 MSEC
PRESENT STIMULUS  NO. 1
                              (APSTIM)--S APPREHENDS ARG1 FROM ARG2
                                   ARGS=ASTM,LITE,NULL,NULL

WAIT FOR 1
 S'S RESPONSE
                              (CLOIR) --S INTEGRATES ARG1 FROM ARG2
                                   ARGS=ISTM,ASTM,NULL,NULL
                              (REPFRM)--S FORMS ARG1 IN MEM FROM ARG2
                                   ARGS=COLR,ISTM,NULL,NULL
                              (FICORP)--S FINDS ARG1=COREP FOR ARG2
                                        (& ARG3) ON BASIS OF ARG4
                                   ARGS=POSN,COLR,NULL,POSN
                              (FICORP)--S FINDS ARG1=COREP FOR ARG2
                                        (& ARG3) ON BASIS OF ARG4
                                   ARGS=HAND,POSN,NULL,MOVT
                              (XECUTR)--S EXECUTES ARG1 FROM ARG2
                                        ON BASIS OF ARG4
                                   ARGS=PUSH,HAND,NULL,OVRT
COMPUTE AND NOTE TIME OF INTERVAL
 RT=  000 MSEC
NOTE S'S RESPONSE, TYPE=
 CHOICE
NOTE S'S SUCCESS/ACCURACY
 CHOICE
AGAINST MAXIMUM, TEST:
 TRIAL # FOR BLOCK/SET
INCREMENT:
 TRIAL # FOR BLOCK/SET
PROCEED TO NEXT TRIAL
                              (ATSTIM)--S ATTENDS ARG1 WITH ARG2
                                   ARGS=SRCE,ELIT,NULL,NULL
NOTE: NEXT TRIAL
SELECT RANDOM INTERVAL OVER  3 POSSIBILITY(=IES)
 FOR INTERTRIAL INTERVAL
SELECT STIMULUS # RANDOMLY FROM  2 POSSIBILITY(=IES)
 WITH REPLACEMENT(NO CONSTRAINT)

**************************************************************************
```

FIGURE 4

```
****************************************************************************
   EXPERIMENTER'S ACTIONS     SUBJECT'S  COGNITIVE PROCESSES AND RESPONSES
   ----------------------     ---------------------------------------------

PRESENT INSTRUCTIONS(SPLAN)
 --GENERAL INSTRUCTIONS
                             (MONITR)==S SETS ARG1 FROM ARG2
                                      ON BASIS OF ARG4
                                 ARGS=SPLN,INST,NULL,ARG
                             (REPFRM)==S FORMS ARG1 IN MEM FROM ARG2
                                 ARGS=ESIS,INST,NULL,NULL
                             (REPFRM)==S FORMS ARG1 IN MEM FROM ARG2
                                 ARGS=ELIT,INST,NULL,NULL
                             (REPFRM)==S FORMS ARG1 IN MEM FROM ARG2
                                 ARGS=SIZE,INST,NULL,NULL
                             (FOCORP)==S FORMS ARG1=COREP FOR ARG2
                                      (& ARG3) ON BASIS OF ARG4
                                 ARGS=MOVP,POSL,NULL,POSN
NOTE: NEXT EXPER. VARIATION
NOTE: NEXT TRIAL
                             (XECUTR)==S EXECUTES ARG1 FROM ARG2
                                      ON BASIS OF ARG4
                                 ARGS=HOME,INST,NULL,NULL
                             (ATSTIM)==S ATTENDS ARG1 WITH ARG2
                                 ARGS=BRCT,ESIS,NULL,NULL

****************************************************************************
   EXPERIMENTER'S ACTIONS     SUBJECT'S COGNITIVE PROCESSES AND RESPONSES
   ----------------------     ---------------------------------------------

EXP.VAR= 1, TOT.TRIAL #= 1, TRIAL # THIS BLOCK= 1
SELECT RANDOM INTERVAL OVER CONTINUUM  1000 TO 4000 MSEC
 FOR BETWEEN WARNING & STIM.
SELECT STIMULUS # RANDOMLY FROM  : POSSIBILITY(=IES)
 WITH REPLACEMENT(NO CONSTRAINT)
PRESENT TIME INTERVAL
 BETWEEN TRIALS
  DURATION= 2000 MSEC
PRESENT SIGNAL:
 TONE
  DURATION= 1000 MSEC
                             (APSTIM)==S APPREHENDS ARG1 FROM ARG2
                                 ARGS=ASTM,TONE,NULL,NULL
                             (ATSTIM)==S ATTENDS ARG1 WITH ARG2
                                 ARGS=BRCL,ELIT,NULL,NULL

PRESENT TIME INTERVAL
 BETWEEN SIGNAL AND STIMULUS
  DURATION= 1000 MSEC
PRESENT STIMULUS  NO.  4
WAIT FOR :
 S'S RESPONSE
                             (APSTIM)==S APPREHENDS ARG1 FROM ARG2
                                 ARGS=ASTM,LITE,NULL,NULL
                             (CLOSR) ==S INTEGRATES ARG1 FROM ARG2
                                 ARGS=ISTM,ASTM,NULL,NULL
                            ~~(REPFRM)==S FORMS ARG1 IN MEM FROM ARG2~~
                                 ARGS=REPI,ISTM,NULL,NULL
                             (FICORP)==S FINDS ARG1=COREP FOR ARG2
                                      (& ARG3) ON BASIS OF ARG4
                                 ARGS=PSNJ,REPI,NULL,POSN
                             (XECUTR)==S EXECUTES ARG1 FROM ARG2
                                      ON BASIS OF ARG4
                                 ARGS=FNSJ,PSNJ,NULL,POSN
                             (XECUTR)==S EXECUTES ARG1 FROM ARG2
                                      ON BASIS OF ARG4
                                 ARGS=MOVH,HOME,NULL,AUTO
COMPUTE AND NOTE TIME OF INTERVAL
 DT(DECISION TIME)=  606 MSEC
                             (XECUTR)==S EXECUTES ARG1 FROM ARG2
                                      ON BASIS OF ARG4
                                 ARGS=MOVJ,FNSJ,NULL,AUTO
                             (XECUTR)==S EXECUTES ARG1 FROM ARG2
                                      ON BASIS OF ARG4
                                 ARGS=PUSH,MOVJ,NULL,OVRT
COMPUTE AND NOTE TIME OF INTERVAL
 MT(MOVEMENT TIME)=  430 MSEC
NOTE S'S RESPONSE, TYPE=
 CHOICE
NOTE S'S SUCCESS/ACCURACY
 CHOICE
AGAINST MAXIMUM, TEST:
 TRIAL # FOR BLOCK/SET
INCREMENT:
 TRIAL # FOR BLOCK/SET
PROCEED TO NEXT TRIAL
NOTE: NEXT TRIAL
                             (XECUTR)==S EXECUTES ARG1 FROM ARG2
                                      ON BASIS OF ARG4
                                 ARGS=HOME,INST,NULL,NULL
                             (ATSTIM)==S ATTENDS ARG1 WITH ARG2
                                 ARGS=BRCT,ESIS,NULL,NULL

****************************************************************************
```

FIGURE 5

```
**************************************************************************
    EXPERIMENTER'S ACTIONS    SUBJECT'S  COGNITIVE PROCESSES AND RESPONSES
    ----------------------    --------------------------------------------

PRESENT INSTRUCTIONS(SPLAN)
 --GENERAL INSTRUCTIONS
                             (MONITR)--S GETS ARG1 FROM ARG2
                                         ON BASIS OF ARG4
                                  ARGS=SPLN,INST,NULL,ANS
                             (REPFRM)--S FORMS ARG1 IN MEM FROM ARG2
                                  ARGS=EANA,RANA,NULL,NULL

NOTE: NEXT EXPER. VARIATION
NOTE: NEXT TRIAL
 STIMULUS OR ITEM NO.  1

                                         .
                                         .
                                         .

**************************************************************************
    EXPERIMENTER'S ACTIONS    SUBJECT'S COGNITIVE PROCESSES AND RESPONSES
    ----------------------    -------------------------------------------

EXP,VAR= 3, 101,TRIAL #=  3, TRIAL # THIS BLOCK=  1
PRESENT SIGNAL:
 TONE
  DURATION= 2000 MSEC
                             (XECUTR)--S EXECUTES ARG1 FROM ARG2
                                         ON BASIS OF ARG4
                                  ARGS="RDY,RRDY,NULL,OVRT

PRESENT SIGNAL:
 FIXATION POINT
  DURATION= 1000 MSEC
                             (ATSTIM)--S ATTENDS ARG1 WITH ARG2
                                  ARGS=SRCE,EANA,NULL,NULL

PRESENT STIMULUS  A
                             (APSTIM)--S APPREHENDS ARG1 FROM ARG2
                                  ARGS=ASMA,STMA,NULL,NULL
                             (CLOZR) --S INTEGRATES ARG1 FROM ARG2
                                  ARGS=ISMA,ASMA,NULL,NULL
                             (REPFRM)--S FORMS ARG1 IN MEM FROM ARG2
                                  ARGS=REPA,ISMA,NULL,NULL

PRESENT STIMULUS  B
                             (APSTIM)--S APPREHENDS ARG1 FROM ARG2
                                  ARGS=ASMB,STMB,NULL,NULL
                             (CLOZR) --S INTEGRATES ARG1 FROM ARG2
                                  ARGS=ISMB,ASMB,NULL,NULL
                             (REPFRM)--S FORMS ARG1 IN MEM FROM ARG2
                                  ARGS=REPB,ISMB,NULL,NULL
                             (FICORP)--S FINDS ARG1=COREP FOR ARG2
                                         (& ARG3) ON BASIS OF ARG4
                                  ARGS=NULL,REPA,REPB,INFR

WAIT FOR :
 S'S RESPONSE
                             (XECUTR)--S EXECUTES ARG1 FROM ARG2
                                         ON BASIS OF ARG4
                                  ARGS="RDY,RRDY,NULL,OVRT

COMPUTE AND NOTE TIME OF INTERVAL
 CUE SCORE(TIME)= 1210 MSEC
PRESENT SIGNAL:
 FIXATION POINT
  DURATION= 1000 MSEC
                             (ATSTIM)--S ATTENDS ARG1 WITH ARG2
                                  ARGS=SRCE,EANC,NULL,NULL

PRESENT STIMULUS  C
                             (APSTIM)--S APPREHENDS ARG1 FROM ARG2
                                  ARGS=ASMC,STMC,NULL,NULL
                             (CLOZR) --S INTEGRATES ARG1 FROM ARG2
                                  ARGS=ISMC,ASMC,NULL,NULL
                             (REPFRM)--S FORMS ARG1 IN MEM FROM ARG2
                                  ARGS=REPC,ISMC,NULL,NULL
                             (FICORP)--S FINDS ARG1=COREP FOR ARG2
                                         (& ARG3) ON BASIS OF ARG4
                                  ARGS=RULR,REPA,REPC,MAP
                             (FICORP)--S FINDS ARG1=COREP FOR ARG2
                                         (& ARG3) ON BASIS OF ARG4
                                  ARGS=ESTD,REPC,NULL,APRL

PRESENT STIMULUS  D
WAIT FOR :
 S'S RESPONSE
                             (APSTIM)--S APPREHENDS ARG1 FROM ARG2
                                  ARGS=ASMD,STMD,NULL,NULL
                             (CLOZR) --S INTEGRATES ARG1 FROM ARG2
                                  ARGS=ISMD,ASMD,NULL,NULL
                             (REPFRM)--S FORMS ARG1 IN MEM FROM ARG2
                                  ARGS=REPD,ISMD,NULL,NULL
                             (TSTSIM)--S COMPARES ARG2 & ARG3 ON BASIS
                                         OF ARG4; OUTCOME=ARG1
                                  ARGS=OURP,REPD,ESTD,STCT
                             (FICORP)--S FINDS ARG1=COREP FOR ARG2
                                         (& ARG3) ON BASIS OF ARG4
                                  ARGS=RYES,OURP,NULL,NAME
                             (XECUTR)--S EXECUTES ARG1 FROM ARG2
                                         ON BASIS OF ARG4
                                  ARGS="YES,RYES,NULL,OVRT
COMPUTE AND NOTE TIME OF INTERVAL
 SOLUTION SCORE(TIME)= 1302 MSEC
NOTE S'S RESPONSE, TYPE=
 CHOICE
NOTE S'S SUCCESS/ACCURACY
 CHOICE
AGAINST MAXIMUM, TEST:
 TRIAL # FOR BLOCK/SET
AGAINST MAXIMUM, TEST:
 EXPER. VARIATION NUMBER
INCREMENT:
 EXPER. VARIATION NUMBER
NOTE: NEXT EXPER. VARIATION
NOTE: NEXT TRIAL
 STIMULUS OR ITEM NO.  4

**************************************************************************
```

FIGURE 6

```
PRESENT INSTRUCTIONS(SPLAN)
 --GENERAL INSTRUCTIONS
PRESENT INSTRUCTIONS(SPLAN)
 (FOR THIS EXPER. VARIATION)
                              (MONITR)--$ GETS ARG1 FROM ARG2
                                      ON BASIS OF ARG4
                                  ARGS=SPLN,INST,NULL,NULL
                              (REPFRM)--$ FORMS ARG1 IN MEM FROM ARG2
                                  ARGS=ESIG,INST,NULL,NULL
                              (REPFRM)--$ FORMS ARG1 IN MEM FROM ARG2
                                  ARGS=ESTM,INST,NULL,NULL
                              (REPFRM)--$ FORMS ARG1 IN MEM FROM ARG2
                                  ARGS=EMSN,INST,NULL,NULL
                              (ATSTIM)--$ ATTENDS ARG1 WITH ARG2
                                  ARGS=SRC1,ESIG,NULL,NULL
NOTE: NEXT EXPER. VARIATION
PRESENT TIME INTERVAL
 BETWEEN BLOCKS
  DURATION= 3000 MSEC
 STIMULUS OR ITEM NO.  1
NOTE: NEXT STIMULUS NO.=  1
 INIT.STIM.DURATION=     0 MSEC

****************************************************************************
   EXPERIMENTER'S ACTIONS    SUBJECT'S COGNITIVE PROCESSES AND RESPONSES
   ----------------------    -------------------------------------------

EXP.VAR= 1, TS1,TRIAL #=  1
PRESENT SIGNAL:
 FIXATION POINT
  DURATION= 1000 MSEC
                              (APSTIM)--$ APPREHENDS ARG1 FROM ARG2
                                  ARGS=ASIG,SGNL,NULL,NULL
                              (TSTSIM)--$ COMPARES ARG2 & ARG3 ON BASIS
                                      OF ARG4; OUTCOME=ARG1
                                  ARGS=OUT1,ASIG,ESIG,NULL
                              (ATSTIM)--$ ATTENDS ARG1 WITH ARG2
                                  ARGS=SRC2,ESTM,NULL,NULL
PRESENT STIMULUS  NO.  1
NOTE:
 DURATION=     0 MSEC
                              (APSTIM)--$ APPREHENDS ARG1 FROM ARG2
                                  ARGS=ASTM,STIM,NULL,NULL
                              (TSTSIM)--$ COMPARES ARG2 & ARG3 ON BASIS
                                      OF ARG4; OUTCOME=ARG1
                                  ARGS=OUT2,ASTM,ESTM,NULL
WAIT FOR :
 S'S RESPONSE
                              (CLOZR) --$ INTEGRATES ARG1 FROM ARG2
                                  ARGS=ISTM,ASTM,NULL,PPIC
                                EXPVAR=1,STIM=1,LOGF=-4.0
                                 (STRENG=0.0064 VDT=   0.0,TVDT=   0.3,500,1076)
                              (XECUTR)--$ EXECUTES ARG1 FROM ARG2
                                      ON BASIS OF ARG4
                                  ARGS="NO",RNO ,NULL,OVRT
                              (ATSTIM)--$ ATTENDS ARG1 WITH ARG2
                                  ARGS=SRC1,ESIG,NULL,NULL
NOTE S'S SUCCESS/ACCURACY=0
 FREE RESPONSE
AGAINST MAXIMUM, TEST:
 DURATION FOR STIMULUS
INCREMENT:
 DURATION FOR STIMULUS

****************************************************************************
   EXPERIMENTER'S ACTIONS    SUBJECT'S COGNITIVE PROCESSES AND RESPONSES
   ----------------------    -------------------------------------------

EXP.VAR= 1, TS1,TRIAL #=  2
PRESENT SIGNAL:
 FIXATION POINT
  DURATION= 1000 MSEC
                              (APSTIM)--$ APPREHENDS ARG1 FROM ARG2
                                  ARGS=ASIG,SGNL,NULL,NULL
                              (TSTSIM)--$ COMPARES ARG2 & ARG3 ON BASIS
                                      OF ARG4; OUTCOME=ARG1
                                  ARGS=OUT1,ASIG,ESIG,NULL
                              (ATSTIM)--$ ATTENDS ARG1 WITH ARG2
                                  ARGS=SRC2,ESTM,NULL,NULL
PRESENT STIMULUS  NO.  1
NOTE:
 DURATION=    10 MSEC
                              (APSTIM)--$ APPREHENDS ARG1 FROM ARG2
                                  ARGS=ASTM,STIM,NULL,NULL
                              (TSTSIM)--$ COMPARES ARG2 & ARG3 ON BASIS
                                      OF ARG4; OUTCOME=ARG1
                                  ARGS=OUT2,ASTM,ESTM,NULL
WAIT FOR :
 S'S RESPONSE
                              (CLOZR) --$ INTEGRATES ARG1 FROM ARG2
                                  ARGS=ISTM,ASTM,NULL,PPIC
                                EXPVAR=1,STIM=1,LOGF=-4.0
                                 (STRENG=0.0064 VDT=   0.0,TVDT=   0.3,500,1076)
                              (REPFRM)--$ FORMS ARG1 IN MEM FROM ARG2
                                  ARGS=RSTM,ISTM,NULL,NULL
                              (FICORP)--$ FINDS ARG1=CORSP FOR ARG2
                                      (& ARG3) ON BASIS OF ARG4
                                  ARGS=RNME,RSTM,NULL,NAME
                                NAMLAT=  781 ADJ.'D=  771
                              (XECUTR)--$ EXECUTES ARG1 FROM ARG2
                                      ON BASIS OF ARG4
                                  ARGS="NME,RNME,NULL,OVRT
                              (ATSTIM)--$ ATTENDS ARG1 WITH ARG2
                                  ARGS=SRC1,ESIG,NULL,NULL
NOTE S'S SUCCESS/ACCURACY=1
 FREE RESPONSE
NOTE:
 THRESHOLD VALUE=   10 MSEC
COMPUTE AND NOTE TIME OF INTERVAL
 RT=  781 MSEC
AGAINST MAXIMUM, TEST:
 STIMULUS # FOR BLOCK/SET
NOTE: NEXT STIMULUS NO.=  2
 INIT.STIM.DURATION=     0 MSEC
****************************************************************************
```

FIGURE 7

(CONTINUED ON P. 61)

```
J.B.CARROLL           PJ=516                 24-MAR-80  16:20:23

REPORT, DATA FROM SIMULATED EXPERIMENT, DATA NAME:  WNGFLD.

TRIAL   EXP.    STIM STIM DUR,,OUTCOME  REP'D   EST'D EST'D NAMING  ADJ'D
  #     VAR#      #  PRESENTD  1=SUCCESS  VDT     VDT  TVDT LATENCY LATENCY

   1     1        1        5         0       0       9     9      0       0
   2     1        1       10         1      10       9     9    781     771
   3     1        2        5         0       0      15    13      0       0
   4     1        2       10         0       0      15    13      0       0
   5     1        2       15         1      15      15    13   1030    1016
   6     1        3        5         0       0      22    25      0       0
   7     1        3       10         0       0      22    25      0       0
   8     1        3       15         0       0      22    25      0       0
   9     1        3       20         0       0      22    25      0       0
  10     1        3       25         1      25      22    25   1258    1254
  11     2        1       80         0       0      93    93      0       0
  12     2        1       85         0       0      93    93      0       0
  13     2        1       90         0       0      93    93      0       0
  14     2        1       95         1      95      93    93    905     812
  15     2        2       80         0       0     104   104      0       0
  16     2        2       85         0       0     104   104      0       0
  17     2        2       90         0       0     104   104      0       0
  18     2        2       95         0       0     104   104      0       0
  19     2        2      100         0       0     104   104      0       0
  20     2        2      105         1     105     104   104   1102     990
  21     2        3       80         0       0     115   115      0       0
  22     2        3       85         0       0     115   115      0       0
  23     2        3       90         0       0     115   115      0       0
  24     2        3       95         0       0     115   115      0       0
  25     2        3      100         0       0     115   115      0       0
  26     2        3      105         0       0     115   115      0       0
  27     2        3      110         0       0     115   115      0       0
  28     2        3      115         1     115     115   115   1300    1105
```

Explanation: The previous page (p. 60) shows the computer printout for the "instructions" section and the first two trials of a simulated experiment embodying a combination of Paradigms 1 and 5, following Wingfield's (1968) procedure. These trials are for "Experimental Variation 1" in which picture stimuli are presented without a following visual mask. In trial 1, a picture whose name has a log probability of -4.0 is presented for a duration of 5 msec. In the CLOZR process, it is determined that such a stimulus would require a visual duration of 9 msec to be recognized and named; therefore, it is assumed that the subject fails to name the picture, and reports that failure in the XECUTR process just below. In trial 2, the stimulus duration is increased to 10 msec and the CLOZR process is therefore successful; the FICORP process also is successful, with a naming latency of 781 msec (determined as a function of name-word probability).

The above table (produced at the end of the computer run) summarizes results for all 28 trials of the simulated experiment. The $\log_{10}$ probabilities of the names for the 3 stimuli are -4.0, -5.3, and -6.6, respectively. Whereas Experimental Variation 1 presents pictures without a following visual mask, Experimental Variation 2 presents a visual mask immediately following the picture presentation; the parameters for estimating VDT (visual duration threshold) are different from those in Experimental Variation 1. For each stimulus, stimulus duration is increased in 5 msec steps until it equals or exceeds the predicted VDT, at which point "successful" picture naming occurs. Reported VDT's are shown in column 6. Predicted VDT's and naming latencies are shown in columns 7 and 9, respectively, with certain adjusted values in columns 8 and 10.

FIGURE 7
(CONTINUED)

illustrate how parameters contained in SPLAN subroutines might be used to predict or test experimental outcomes. In this experiment, VDTs and picture-naming latencies were determined as a function of the word-frequencies of the picture names, both with no post-stimulus masking and with post-stimulus masking. This ECT illustrates our Paradigm 1, and in the picture-naming data, Paradigm 5. From Wingfield's graphed data, parameters were worked out for predicting VDTs and picture-naming latencies. By making certain assumptions about the persistence of the visual image under no masking and masking conditions and about the time for initiating a vocalization, it might be possible to estimate parameters separately for CLOZR, FICORP, and XECUTR processes.

Although not implemented as yet, code for moderating parameters with individual difference data could be inserted in SIMCOG.

Use of Cognitive Task Paradigms in Assessing Cognitive Processes

We now need to retrace the ground we covered in describing the eight cognitive task paradigms that were identified in an earlier part of this chapter, to assess the ways in which these paradigms can be used to study the 10 cognitive processes that have been set forth. Our interest in individual differences makes it particularly desirable to be able to assess each of these 10 processes separately, because it is at least conceivable that individual differences in these processes are to some extent independent of each other. We need to be able to investigate this matter.

This section is organized mainly around the paradigms themselves, because as will be seen, observations and measurements taken for each of the paradigms typically reflect the combined operation of several processes. We need to see whether data from different paradigms can be collected and analyzed in such a way as to identify the separate contributions of each process.

A main focus of interest in cognitive psychology is the time that each process takes. Studies of individual differences would therefore look for reliable variations in processing times over individuals. The general assumption in "mental chronometry" (a term used by Posner, 1978) is that information processing proceeds in a series of stages, and that the total time observed from the initiation of a cognitive task can be analyzed in terms of the time taken by each of the stages. Nevertheless, it may be that the stages overlap and interact in such a way that it is difficult or meaningless to attempt timing them separately. Pachella (1974) has discussed many of the problems in interpreting reaction time data and seems to conclude that while the various methods (the Additive Factor method, the Subtraction method, etc.) all have certain faults, the method of "converging operations," i.e. the accumulation of evidence from a variety of related studies, can be expected eventually to produce scientifically valid results and interpretations. This is the stance adopted here, in that we attempt to suggest how information from the various paradigms can be compared in such a way as to produce reasonably firm conclusions. We need also to recommend procedures and measurements that will be more likely to facilitate such comparisons. Our survey of available literature on IDs in cognitive task discloses a frustratingly large lack of uniformity in procedures.

Although there will be a heavy emphasis on measures of processing time, measures concerned with the correctness of response, or its complement, error rate, cannot be ignored. In many of the simpler paradigms, however, error rates are typically so low that there is little possibility of significant individual difference variance in them.

Paradigm 1: The Perceptual Apprehension paradigm. In the most general terms, the object of this paradigm is to determine thresholds of various sorts.

One kind of threshold is the minimal stimulus energy that is necessary to produce perceptual apprehension (and also the formation of a representation). By Bloch's law, that stimulus energy is a joint function of intensity and duration, but in cognitive psychology the interest is usually in the temporal parameter alone when intensity is held constant at some "reasonable" level (e.g. field luminance of 32 mlam. in a visual duration threshold experiment; Richards & Platnick, 1974). Using the method of ascending limits, with small increments in time of exposure on each trial, one determines the minimal duration necessary to produce a positive report in the subject. (For greater precision, it may be suggested that one-half of the duration increment should be subtracted from the minimal duration determined in this way.) But the minimal duration cannot necessarily be the time taken up by the processes we have called here APSTIM, CLOZR, and REPFRM; it is simply the stimulus energy necessary to activate these processes. How long do these processes take?

A possible solution to this problem comes from the fact that duration thresholds obtained when the stimulus exposure is followed (and sometimes preceded) by a mask (e.g., of random lines and curves, in a visual duration experiment) are regularly longer than those obtained without masking. Presumably, the mask blocks the operation of any iconic image that persists after a stimulus exposure. Therefore, the duration threshold obtained with masking must be the time taken up by the processes APSTIM, CLOZR, and REPFRM _with masking_. To determine the time taken up by these processes _without_ masking, we must appeal to other kinds of information obtainable from the paradigm.

It is interesting to note, at this point, that times taken up by processes during duration thresholds do not include any time that may be required for the subject's report; thus, they do not include time for processes such as FICORP or XECUTR. Times for these processes, however, _are_ included in determinations of time of report after a short exposure. We can compare these time determinations for no-masking vs. masking to get an estimate of the additional time taken by APSTIM, CLOZR, and REPFRM with masking as opposed to without masking. For example, if we examine (with some reanalysis) Wingfield's (1968) data on visual duration thresholds for pictures with and without masking and on latencies of picture naming, we find that for picture name-words of average frequency, the naming latency was about 1102 msec, as opposed to 1030 msec without masking. If we assume that the times for such processes as FICORP and XECUTR were the same under the two conditions, the difference in latencies should give an estimate of the additional time required for completion of APSTIM, CLOZR, and REPFRM masking as opposed to no masking, i.e. 72 msec. Since the VDT under masking averages at 104 msec (with very little variation over name-word frequencies), we subtract 72 msec to obtain an estimate of 32 msec for the APSTIM, CLOZR, and REPFRM processes to be completed under no masking (which is 17 msec longer than the VDT of about 15 under no masking).

It would be interesting to experiment with this paradigm, making computations such as suggested here, using stimuli that are more than normally difficult to integrate, such as the Street Gestalt test pictures, or the words in Thurstone's Mutilated Words test. Using such materials, it might be possible to differentiate times for APSTIM, CLOZR, and REPFRM by obtaining different kinds of subject reports (e.g., mere apprehension of the stimulus, vs. completion of integration, vs. the name of the stimulus).

It can be expected that the parameters of processes involved in this paradigm will be a function of stimulus characteristics as well as individual differences.

Paradigm 2: The Reaction Time and Movement Time paradigm. Our main concern with this paradigm is that the experimental arrangements should always make it possible to separate decision time from movement time. This can be done by having the subject start from a constant position in making his response, and measuring the reaction (or decision) time from the onset of the stimulus to the onset of the response of leaving the constant position. Decision time measured in this way includes times for APSTIM, CLOZR, and XECUTR (this last process conceived of as the planning of a response). If desired, movement time can be measured as the time for a continuation of the XECUTR response.

The difference between simple reaction time and choice reaction time seems to consist in the number of bits of information that must be processed (0 bits for simple reaction time and $\log_2$ [set size] for choice RT). It is not yet clear exactly how the set size influences choice reaction time; we have suggested above that it has to do with an attentional process, i.e. with ATSTIM, and not with a search process as such. But does ATSTIM influence FICORP processes or XECUTR processes? Possibly it influences both, to some extent. As an illustration of the kind of data that might be used to illuminate this question, consider the wide variation in time per bit (i.e., the slope of RT on set size) in different experiments. In Jensen's (1979) experiment on a choice reaction time task in which the subject's only task was to push a button next to a light, the time per bit averaged about 23 msec. It may be assumed that there was minimal FICORP or "look-up" process; possibly set size influenced mainly the XECUTR process (selecting which movement to plan). In Keating and Bobbitt's (1978) simple and choice reaction tasks, there must have been at least one FICORP operation to retrieve the position (left or right) corresponding to the light (red or green); time per bit (which cannot be very well estimated from the data because points are available only for 0 and 1 bit) was 234 for average ability 17-year olds, and 195 for high ability 17-year olds. In Carroll's (1975) study of absolute pitch ability, data points were available at 0, 2, 4, and 6 bits; the average time per bit for 4 subjects with absolute pitch ability was 109 msec. This figure could have been due to the fact that, as suggested by logical analysis of the task, there were two FICORP processes necessary in any choice: (1) retrieving the identity of the heard note; (2) retrieving the position of that note on the piano keyboard. Experimental variations of Carroll's absolute judgment task might permit differentiating these two processes.

Paradigm 3: The Evaluation/Decision paradigm. Latency measurements taken from this paradigm, by noting the time from the onset of the stimulus to the onset of the subject's response (preferably using the "home position" procedure mentioned earlier) would include times for the usual APSTIM, CLOZR, and REPFRM processes. (One could also use masking procedures to better investigate the times of these processes.) It will also generally involve at least one FICORP process in which the subject has to evaluate the stimulus with respect to some rule given as an argument in the FICORP process. An example of a simple Paradigm 3 task is one used by Anderson and Reder (1974), adapted from a task originated by Moore (1915), the time to report "thinking of the meaning of a word" presented visually. Average latencies (over a sample of words) reported by Anderson and Reder were 518 msec for "instance words" and 496 msec for "category words." When, however, there was a lexical decision involved--the instance and category words being presented interspersed with nonwords, the average latencies were considerably higher: 739 for instance words and 641 for category words. The usual interpretation of such a result has been that the lexical decision task involves some kind of search of memory; while this may be the case, it is also possible that there is a set-size effect, in that two alternative responses are possible. Support for the notion that there is also a retrieval process (FICORP) comes from the fact that it is regularly found, in lexical decision experiments, that the latencies are longer for nonwords as opposed to words. For example, in applying a task due to Meyer, Schvaneveldt, and Ruddy (1974), Rose and Fernandes (1977) found average lexical decision latencies for words as 736 and for nonwords as 916; these were data for day 1. On day 2 the latencies decreased somewhat to 647 for words and 756 for nonwords, a finding that suggests that by day 2 much less search process was necessary because the nonwords had been by that time learned as such. In any case, it seems that the main value of Paradigm 3 can be in investigating times required for FICORP processes as a function of the stimulus characteristics, the requirements of the task, and practice and repeated exposure.

Paradigm 4: The Stimulus-Matching/Comparison paradigm. As compared to Paradigm 3, Paradigm 4 introduces a new process: TSTSIM, i.e. the explicit comparison of two stimuli on the basis of some rule for the comparison. We would, therefore, expect latencies to be greater from tasks in this category. Unfortunately, there is much lack of uniformity in conducting experiments following this paradigm, and experimenters fail to exploit the possibility of the paradigm sufficiently. There are two major problems: (1) There is usually failure to use the "home position" technique to exclude variance in movement time, and (2) two stimuli are often presented simultaneously when they need not be, and thus there is possibly unwanted variance in the processing of the first stimulus. If stimuli can be presented successively (and separately) the latency of report from the onset of the second stimulus can exclude processing time for the first stimulus. It will, of course, contain time for the TSTSIM operation, and there is a strong possibility that the amount of time for the TSTSIM operation can be ascertained by comparing the latency for the second stimulus with that of the first stimulus. The latter would be obtained by some form of Paradigm 3 procedure, e.g. asking the subject to report when the first stimulus has been encoded, and initiating presentation of the second stimulus only when the subject has reported "encoding" of the first stimulus.

(An example of an experiment that did follow this procedure is that of Clark & Chase, 1972; they were able not only to obtain data on the encoding of the first stimulus [a sentence] but also to compute parameters for selected aspects of the FICORP and possibly TRAREP processes in the second phase of the task.)

The data on encoding of the first stimulus would often be valuable in themselves. Under successive presentation, we would expect the latencies to be systematically faster than under simultaneous presentation, but at this writing no data can be found in the literature to test this assumption, because of lack of comparability in experimental procedures across studies.

We have classified various types of memory experiments under this paradigm, e.g. the Sternberg task in which there is presumably a search of short-term memory for match with a "probe stimulus." In our terms the search of short-term memory would be interpreted as a group of TSTSIM operations--we use the term "group" rather than "series" because we do not want to commit ourselves as to whether these are serial or parallel processes. Because the usual finding is that latency of response to the probe is linearly related to the memory set size, rather than to its logarithm, it appears that this is not a function of attentional processes in the way that the choice-reaction task is affected. Nevertheless, one might consider that there is still a choice reaction aspect of the task in the sense that "yes" and "no" alternatives are possible, and the regular finding that "no" responses take longer may be a function of this two-choice aspect, influencing the XECUTR segment of the process. The slope of the function relating response latency to memory set size may be interpreted as a measure of the time to perform a TSTSIM operation.

The recognition paradigm, as exemplified in the Shepard and Teghtsoonian (1961) task used by Rose and Fernandes (1977) in their information processing battery, is also regarded as falling under our Paradigm 4, in that it involves continual testing of new stimuli for the possibility that they are also "old" stimuli previously presented. Here the interest is not in latencies but in the correctness of the responses. An appropriate measure of the probability of correct response, as a function of lag, is

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the parameter B in the equation $y = Ax^B$, or in its logarithmic form $\log y = \log A + B \log x$.

Paradigm 5: The Naming/Reading/Association paradigm. As compared to the previous paradigms, this paradigm introduces FICORP processes that are considerably more complex and extensive relative to those which may occur in the previous paradigms (except in the case of requiring naming or reading responses in Paradigm 1). Even reading times, which are generally faster than naming times, demand that the subject retrieve a complex vocal response, as opposed to the mere search of memory for representations of seen or heard words with only the requirement of judging meaningfulness or similarity through a binary report. Latencies for reading, naming, and association times can be studied as a function of various stimulus characteristics, priming, practice, and task instructions (e.g., various types of controlled associations); effects of other processes such as APSTIM, CLOZR, and REPFRM would be partialled out on the basis of results from other paradigms.

The Stroop task (Stroop, 1938) presents an interesting special case because it appears to involve a conflict of reading and naming responses. There are many ways of scoring the Stroop task (for discussions, see Thurstone, 1953; Jensen & Rohwer, 1966); we would favor those that take account of the separate strengths of color and reading responses and on this basis measure the amount of conflict existing between the two types of responses when the color-word task is presented. As we have suggested, the conflict can perhaps be conceptualized as the result of an automatic TSTSIM operation that gives a negative outcome when the color and word responses do not produce the same reps.

Paradigm 6: Episodic Memory Readout. This paradigm characteristically involves the evaluation of FOCORP processes, i.e. processes whereby new representations and co-representations are formed, and in the testing phases, FICORP processes, wherein the representations formed in the learning phase are retrieved. Little use is made of latency measurements; rather, measurements are primarily of the probabilities of correct recall and retrieval. In the memory span subparadigm, the concern is with how many representations can be formed in short-term memory and then retrieved.

Paradigm 7: Analogical Reasoning. R. Sternberg (1977) has already presented such an elaborate and complete analysis of this paradigm that it would be gratuitous to offer much more here, except possibly a reinterpretation of some of his "components" in our terms. Furthermore, the analogical reasoning task has already been treated here both by DTR chart and by a SIMCOG program (Figures 3 and 6).

Encoding: This is equivalent to our REPFRM, except that in the analogical reasoning task, encoding is not only of the meaning of the terms but also of the attributes and values of the terms. Each such encoding involves a separate REPFRM, each with its own arguments.

Inference: Insofar as this involves "discovering a rule relating A and B," this involves TSTSIM and FICORP processes in which attributes of A and B are noted, compared, and referred to memory to find a representation of a rule that relates them.

Mapping: This is similar to Inference, except that it applies to the A and C terms of the analogy.

Application: This is a FICORP process in which the argument, BSIS, is the outcome of the Inference process.

Justification: This seems to be a further type of Application operation in which when the straightforward application process does not quite succeed, adjustments are made in the representations (possibly by our TRAREP process) in order to make it successful.

Preparation-response: This seems to correspond to our MONITR process; it is essentially the process by which the subject acquires a knowledge of the structure of the task and monitors his performance in it. It also involves the XECUTR process.

Paradigm 8: Algorithmic Manipulation. This paradigm has such a large number of variants that it is difficult to identify any particular processes that are featured in it, except possibly various types of FICORP processes. For example, in the

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"Sunday + Tuesday" task studied by Hunt, Lunneborg, and Lewis (1975), there appears to be a FICORP process in an encoding phase of the task; the subject is given, say, a day of the week and has to find a corresponding number for that day; when he has done so, he presses a button indicating readiness to continue. The time from onset of the stimulus to the button press can be regarded as primarily a function of the FICORP process. In the solution phase, there are further FICORP processes in which another day of the week has to be encoded as to its number; the two numbers are added (again by a FICORP process), the sum is converted to a number modulo 7, and the resulting number is converted back to a day of the week. As these authors use the task, the solution time is the total time to attain the solution starting from the onset of the second stimulus, but it would also be possible to break this phase down into subphases in order to study the times taken by each FICORP process involved.

An Illustrative Series of Proposed Experiments

We complete this chapter by proposing a series of experiments intended to illustrate the possibility of estimating various parameters of the cognitive processes proposed here. This series of experiments would use a common set of materials--pictures and the words that name those pictures. The pictures would be drawn primarily from the Street Gestalt Completion test, but both clear and mutilated forms of these pictures would be used. Further, both "clear" and mutilated forms of the words would be used (like the "mutilated words" in Thurstone's test of that name). The words could be presented in both capital letter and lower-case forms. (It appears that the literature of word-recognition thresholds generally concerns recognition of capital letter forms, ignoring the fact that it was shown long ago [Tinker & Paterson, 1928] that words in "all caps" are harder to read than the same words in lower-case letters.) The series of experiments would then be conducted according to the various paradigms we have identified.

Paradigm 1: Visual duration thresholds would be determined both without masking and with masking for the

1. "Clear" pictures
2. "Mutilated" pictures (as in the Street Gestalt Completion test)
3. "Clear" capital letter words
4. "Mutilated" capital letter words
5. "Clear" lower case words
6. "Mutilated" lower case words

In each case, however, there would be several types of subject reports affecting the determination of the visual duration thresholds:

(a) Report of mere awareness of the stimulus (without necessarily its perceptual integration)

(b) Report of the integration of the stimulus (but without naming or reading it)

(c) Naming or reading of the stimulus

The purpose of this part of the experiment would be to determine parameters for APSTIM, CLOZR, and REPFRM for the various stimuli. Here, we mean both parameters for the average subject and stimulus and parameters for individual subjects and stimuli.

Paradigm 2: The stimuli used in the Paradigm 1 experiments would also be used as the stimuli for a series of simple and choice reaction experiments. For example, a choice reaction experiment could be based on deciding which of a series of pictures or words is presented; a two-choice experiment could be based on whether the stimulus is "clear" or "mutilated"; etc. The design of these experiments would make it possible to isolate separate parameters for the FICORP and XECUTR processes that would be involved.

Paradigm 3: With indefinite stimulus exposures, clear and mutilated pictures would be judged for "sense," along with "non-pictures" (analogous to the pseudowords in lexical decision tasks). Similarly, lexical decision tasks would be given for the words, using both clear and mutilated nonwords, in both capital and lower-case print.

Paradigm 4: Various kinds of matching tasks would be given (analogous to those used by Wingfield [1968]) to explore the function of the TSTSIM process. Both simultaneous and successive presentation methods would be used; in the successive presentation tasks, encoding times would be taken in the first phase of the task. Picture-picture matching could include combinations of clear and mutilated pictures, in different orders; picture-word and word-picture matching would also be given.

Paradigm 5: Anything in this paradigm would have been taken care of, presumably, in the naming and reading phases of Paradigm 1.

Paradigm 6: Various types of tasks could be employed in this paradigm: memory span (for words), probed memory search (the Sternberg task), running recognition tasks, etc. The purpose would be to explore the parameters of the FOCORP process, given parameters of the other processes determined from other paradigms.

Paradigm 7: Possibly the stimuli used in the other tasks would lend themselves to the construction of analogies, in which case R. Sternberg's procedures would be used to determine parameters for components. These parameters would be compared with those obtained in other paradigms.

Throughout, attention would be given to individual differences. A correlational analysis of the various parameters determined for individual subjects would be made; also, the correlations with selected psychometric tests would be determined, being careful to distinguish speed and power (level) aspects of these tests. Also, attention would be paid to the reliabilities of the parameters over separate testing occasions.

This series of experiments should provide ample opportunity to test the ideas about cognitive processes advanced here, and it would also shed light on the problem of identifying individual differences in the parameters of cognitive processes.

Chapter 3

INDIVIDUAL DIFFERENCES IN ELEMENTARY COGNITIVE TASKS: THE VIEW FROM FACTOR ANALYSIS

Introduction

In surveying individual differences (IDs) in elementary cognitive tasks (ECTs), we have chosen to focus attention on a specified set of studies in recent literature. This set was chosen from the large corpus of studies and references mentioned in Chapter 1 (pp. 3-5) to include mainly studies that present data on IDs in ECTs of the types that have been classified according to the eight paradigms described in Chapter 2. Emphasis was placed on studies that present data on means, variances, and reliabilities of variables measuring individual performances on these tasks, correlations among such variables, and/or correlations between performances on these tasks and the more traditional psychometric measures. The list of the 55 studies included in this survey is shown in Table 1, which indicates the nature of the subject samples utilized in each case, the cognitive tasks studied (identified by the names used in the studies themselves and then classified by paradigm), and the correlative measures, if any, on which data were obtained. In all, 197 instances of ECTs were included in these studies; some of these instances are identical or highly similar, but they exhibit in general great variety. Classified according to our eight paradigms, they show the following frequencies of occurrence in the studies:

Paradigm 1: Perceptual apprehension	12
Paradigm 2: Reaction time and movement	16
Paradigm 3: Evaluation/decision	5
Paradigm 4: Stimulus matching/comparison	67
Paradigm 5: Naming/reading/association	14
Paradigm 6: Episodic memory read-out	67
Paradigm 7: Analogical reasoning	6
Paradigm 8: Algorithmic manipulation	7
Miscellaneous, unclassified	3
	197

TABLE 1

DETAILS ON 55 STUDIES EXAMINED FOR INFORMATION ON IDs IN ECTs

Study	Sample	Laboratory tasks	Paradigm	Correlative measures
Allen, Rose, & Kramer (1978)	N = 68 male & female students answering ad at Georgetown U.	Letter Recall, pp. 5-9 Mental Addition, pp. 9-11 Sentence Recall, pp. 11-13 Sentence Recognition, pp. 13-16 Letter Rotation, pp. 16-18 Physical Match, pp. 18-19 Set Membership, pp. 19-21 Scan and Search, pp. 21-22	6 8 6 4 4 4 4 4	- - -
Berger (1°77)	N = 74 (41 males, 33 females, mean age 19, 17-33), New York U. psychology subject pool	Immediate Digit Span 4-7, p. 55 Proactive Inhibition, p. 55 Retroactive Inhibition, p. 55 Delayed Digit Span 4-7, p. 55 Long Digit Span, p. 58 Immediate Digit Span 2-9, p. 58 Delayed Digit Span 2-9, p. 58	6 6 6 6 6 6 6	Vocabulary, p. 49 Rod and Frame Test, p. 49 Embedded Figures Test, p. 50 Attention Test (questionnaire), p. 59
Bisanz, Danner, & Resnick (1979)	N = 128 (16 males, 16 females at each of 4 levels, gr. 3,5,7, college	Physical & Name Identity Comparisons, Pictures	4	- - -
Butler & Hains (1979)	N = 12 in each of 2 expts; introd. psychol. students sampled to give wide vocab.range	Word Naming, p. 70 Lexical Decision, p. 72	5 3	Vocabulary, pp. 69-70
Chiang & Atkinson (1976)	N = 34 Stanford U. undergraduates (17 males, 17 females)	Memory Search Task, p. 663 Visual Search Task, p. 664 Digit Span Task, p. 664	4 4 6	SAT-V, SAT-M, p. 663
Cohen (1976)	N = 30 male & female freshmen, introd. psychol. courses (Hi-Lo groups)	Word Recognition Threshold,p.472	1	Otis Self-Administering Test (Hi-Lo groups were upper and lower 25%)
Cooper (1976, 1978)	Expt. I: N = 10 Stanford U. students Expt. II: N = 8 Stanford U. students, staff, volunteers	Visual Comparison Task, p. 435	4	- - -
Cory, Rimland, & Bryson (1977)	N = 385 enlisted personnel, Naval Training Center; Ages 17-19; at or above 50th %ile recruit ability distribution	Memory for Objects, p. 102 Memory for Words, p. 102 Visual Memory for Numbers Test, p. 102 Comparing Figures, p. 102 Recognizing Objects, p. 102 Memory for Patterns, p.102 Twelve Questions, p. 102 Password, p. 105	6 6 6 4 1 6 Misc. 5	8 tests drawn largely from ETS Kit Drift Direction test 9 tests from regular Navy personnel battery
Egan (1978)	N = 31 to 48 for different tests; Navy personnel, selected on screening battery that included spatial ability	Spatial Apperception Test, p. 9 Spatial Orientation Test, p. 10 Spatial Visualization, p.10 Block Rotation Test, p. 10 Yes-No Decision Test, p. 21	4 4 4 4 2	- - -
Fernandes & Rose (1978)	N = 22 volunteer AIR staff members	Free recall, pp. 7-11 Running Recognition, pp. 11-15 Interference Susceptibility, pp. 15-21 Situational Frequency, pp. 21-24 List Differentiation, pp. 24-28 Memory Span, pp. 28-35	6 4 6 4 6 6	- - -

TABLE 1 (Continued)

Study	Sample	Laboratory tasks	Paradigm	Correlative measures
Frederiksen, C. (1969)	N = 120 (in 3 groups, 40 each, randomly assigned exptl. conditions), Univ. of Illinois undergrads, grads.	List Learning, p. 13 (3 learning methods: Serial anticipation Codable clusters Free recall	6	13 tests (8 abilities) from 1963 ETS Kit
Frederiksen, J. (1967)	N = 145 male undergrad. & grad.students, Princeton U. (85, 60 in 2 exptl. gps.)	Visual Recognition Test, p. 5 Auditory Recognition Test, p. 5	1 1	27 cognitive tests (8 abilities) from various sources, pp. 3-5
Frederiksen, J. (1978)	N = 20 h.s. sophomores, juniors, & seniors with wide range of reading ability	Letter Matching, pp. 8-11 Bigram Identification, pp. 11-12 Pseudoword Decoding, pp. 12-13 Word Naming, pp. 13-14	4 1 5 5	Nelson-Denny Reading Test, p. 19
Goldberg, Schwartz, & Stewart (1977)	N = 40 (10 each in Hi-Lo verbal X sex), from 537 introd. psychol. students, N. Illinois U.	Physical/Homophone/Taxonomic Category Identification, p. 11	4	Verbal battery, Lorge-Thorndike Intelligence Test (College Edition, Form 2)
Hawkins, Church, & de Lemos (1978)	N = 17 (6, 3, 8 in different expts.), U. Oregon paid subject pool	Double-stimulation Choice Reaction Time	2	- - -
Hitch (1978)	N = 138 (30, 30, 39, 39 in 4 expts.), naval ratings, lab. subject panel, staff, age 20-60)	Mental Arithmetic Task	8	- - -
Hock (1973)	N = 24 undergrads, Johns Hopkins U. who passed a 1st day criterion	Reproduction Task, p. 416 Same-Different Comparison Task, p. 417	6 4	- - -
Hock, Gordon, & Corcoran (1976)	N = 56 (24, 32 in 2 expts.), undergrads, Fla. Atlantic U.	Word-Picture Matching	4	- - -
Hock, Gordon, & Gold (1975)	N = 32 (16, 16 in 2 expts.), undergrad. & grad. students, Fla. Atlantic U.	Physical & name matches, alphabetic letters	4	- - -
Hock, Gordon, & Marcus (1974)	N = 64 (32, 32 in 2 expts.), male & female undergrads., Fla. Atlantic U.	Embedded Alphabet Letters	4	- - -
Hock, Gordon & Whitehurst (1974)	N = 32 students, Fla. Atlantic U.	Same-different comparisons, Multiobject Scenes	4	- - -
Hock & Marcus (1976)	N = 16 male undergrad., Johns Hopkins U.	Same-Different Comparisons, Intact vs. Fragmented Letters	4	- - -

TABLE 1 (Continued)

Study	Sample	Laboratory tasks	Paradigm	Correlative measures
Hock & Ross, (1975)	N = 24, undergrad. students, non-students, Fla. Atlantic U.	Same-Different Comparisons, Dot Patterns	4	- - -
Hock, Throckmorton & Colombo (1976)	N = 32 undergrads., Fla. Atlantic U.	Same-Different Comparisons, Words & Pseudowords	4	- - -
		Forced-Choice Recognition Task	4	
Hogaboam & Pellegrino (1978)	N = 40 U. Pittsburgh undergrads.	Semantic category decisions, words, p. 190	4	SAT-V (available for 34 of sample)
		Semantic category decisions, pictures, p. 190	4	
Hunt, Frost, & Lunneborg (1973)	N = 104 freshmen, U. Washington, (upper & lower VA X QA 25% groups)	Continuous Paired Associates, pp. 96-99	6	Pre-College Inventory, U. Washington, Verbal and Quantitative Aptitude Scores
		Clustering (Semantic Category), pp. 99-101	6	
		Encoding (Posner Task), pp.101-102	4	
		Semantic Coding & PI Release, pp. 102-104	6	
		Manipulation of Information in STM (Sternberg Task), pp.104-106	4	
		Susceptibility to Interference (Brown-Peterson Task), pp. 106-108	6	
		Acquisition & Retrieval from LTM, pp. 108-109	6	
Hunt, Lansman, & Wright (1979)	N = 52 U. Washington undergraduates	Raven Matrix Problems with psychomotor secondary task, p. 4	8	- - -
		Language Comprehension with psychomotor secondary task, p. 12	Misc.	
		Continuous Paired Associates with secondary task, p. 18	6	
Hunt, Lunneborg, & Lewis (1975)	N varied, ≈ 49 for a factor analysis; Hi/Low verbal, U. Washington students	Name-identity/Physical-identity, computer display, pp. 200-202	4	Washington Pre-College Inventory Verbal Comprehension Numerical Ability Space Visualization Numerical Reasoning Verbal Reasoning Minnesota Clerical Test (Numbers, Name) Hidden Figures
		Name-identity/Physical-identity, card sort, pp. 200-202	4	
		Recall of "integrable" words, pp. 202-204	6	
		Peterson-Peterson paradigm, pp. 204-206	6	
		Dichotic order judgment, pp.206-9	3	
		Sentence verification (Clark & Chase task), pp. 209-212	4	
		Sunday + Tuesday task, pp. 212-216	8	
		Dichotic listening, pp. 217-218	6	
		Auditory Digit Span, p. 218	6	
		Stroop Test Modification, p. 218	5	
		STM Search Task (Sternberg), p.218	4	
		Iconic Memory (Sperling), p. 219	6	
Hussy & Scheller (1976)	N = 80 female & male students	Stochastic-ergodic prediction task	Misc.	Nonsense Learning Probability Learning Meaningful Learning Fluid Intelligence Crystallized Intelligence Cognitive Complexity scores Stroop-Word-Color (written version)
Jackson & McClelland (1979)	N = 52 freshmen, sophomores at U.Cal.San Diego (24 of which also served in Expt. 2)	Letter Separation, p. 157	1	School and College Aptitude Test, Series II, Form 1C (verbal, quantitative composites), p. 157 Listening Comprehension Test (Paragraphs from SCAT), p. 157
		Single-Letter Threshold, p. 158	1	
		Simple-Pattern Matching, p. 158	4	
		Letter Matching, pp. 158, 175	4	
		Synonym Matching, p. 158	4	
		Homonym Matching, p. 158	4	
		Multiple-Letter Display, p.159	4	
		Auditory Letter-Span, p. 159	6	
		Dot-Pattern Matching, p. 175	4	
		Pseudoword-Homophone matching, p. 176	4	

TABLE 1 (Continued)

Study	Sample	Laboratory tasks	Paradigm	Correlative measures
Jensen (1979)	N = 50 U. Calif. (Berkeley) undergrads.	Reaction Time/Movement Time Apparatus, p. 22 Serial Rote Learning, p.24 Digit Span Memory, p. 24	2 6 6	Raven Advanced Progressive Matrics, p. 24 Terman Concept Mastery Test, p. 24 3 scales of Eysenck Personality Inventory, p. 24
Kail & Siegel (1977)	N = 72 (12 males, 12 females at each of 3 grade levels, gr. 3, 6, college), college Ss in U. Pittsburgh subject pool	Matrix Letter/Position Recall, pp. 341-343	6	- - -
Keating & Bobbitt (1978)	N = 60 (20 in each of grades 3, 7, 11)	Simple & Choice Reaction Time,p.157 Name Retrieval from Memory,p.158 Memory Scanning, p. 160	2 4 4	Raven Standard Progressive Matrices Raven Advanced Progressive Matrices (as appropriate to age group)
Keele, Neill, & de Lemos (1978)	N = 15 (undergraduates?)	Priming, p. 3 Rare Event Task, p. 4 Alternation Task, p. 4 Dichotic Listening Task, p. 5	2 2 2 6	---
Lansman (1978)	N = 112 (48, 40, 24 in 3 expts., Male + Female in Expts. 1,2; Female in Expt. 3); U Washington undergrads, Hi/Lo groups on WPC	Continuous Paired-Associates, with secondary task,pp. 41,46 Digit Span,p. 45 Three-Term Series Problems, pp. 65 ff. Sentence Verification, pp. 66 ff.	6 6 8 4	Verbal Composite, Washington Pre-College Inventory, pp. 40-41
Love (1977)	N = 61 students in computer science courses (U. Washington)	Continuous Paired-Associates, Programming Content, pp. 17-18 Digit Span, pp. 18-19 Perceptual Speed, p. 19 Free Recall Learning, pp.19-20	6 6 4 6	Course Examinations, p. 9 Computer Programming Performance, p. 9 Subjective Reports, p. 16
Lunneborg (1977, Study 1)	N = 64 high-sch. age (33 males, 31 females)	Motor Reaction Time, p. 311 Choice Time, p. 311 Stroop Difference, p. 311 Search Task, p. 311 Digit Span, p. 311 Dichotic Category, p. 312 Semantic Clustering, p. 312	2 2 5 4 6 6 6	Verbal Comprehension, p. 311 Numerical Ability, p. 311 Space Visualization, p. 311 Numerical Reasoning, p. 311 Verbal Reasoning, p. 311 Clerical Number, p. 311 Clerical Name, p. 311 Hidden Figures, p. 311
Lunneborg (1977, Study 2)	N = 63 (27 men, 36 women), 1st year at U. Washington	Binary Choice Reaction Time,p. 319 Delayed Auditory Feedback,p. 320 Raven Response Times, p. 320 Verbal Problem Solving, p. 320	2 5 8 6	Measures & composites, p. 317: Vocabulary Grammar Quantitative Space I Space II Inference Evaluation of Arguments Letter Search Number Checking Code Translation
Lunneborg (1977, Study 3)	N = 64 high school students	Binary Choice Reaction Time,p.324	2	EAS Verbal Comprehension, p. 324 EAS Numerical Ability EAS Numerical Reasoning EAS Verbal Reasoning EAS Symbolic Reasoning Advanced Progressive Matrices (Set II) Maze Tracing Hidden Figures Two Dimensional Spatial Relations(CMAT) Three Dimensional Spatial Relations (CMAT)

TABLE 1 (Continued)

Study	Sample	Laboratory tasks	Paradigm	Correlative measures
Lunneborg (1978)	N = 63 (36 women, 27 men), freshmen, U. Washington, representative of joint distribution of WPC Verbal & Quantitative	Visual Temporal Order Judgment, p. 155 Dichotic Listening Task, p. 155 Delayed Auditory Feedback, p. 156 R/L Conversion Reading Task, p. 156 Raven Time (probs. 8 & 9),p. 156 Fact Retrieval, p. 157	3 3 5 5 8 6	Vocabulary, p. 154 Raven's Advanced Progressove Matrices, p.154 WAIS Verbal, Performance, Full Scale IQs (pp. 154-155)
MacLeod, Hunt, & Mathews (1978)	N = 70 undergrads, U. Washington	Sentence-picture comprehension	4	Form A, Nelson-Denny Reading Test - Comprehension Level WPC (Washington Pre-College Test): Verbal Composite Spatial Composite (all pp. 495-496)
Malmi, Underwood & Carroll (1979)	N = 97 college students (Northwestern Univ.)	Free Recall series, FR1,FR3, FRS Serial Learning, SL1, SL3, SLS Paired Associate, PA1, PA3, PAS, PA-12St, PA-4St, PA-25t	6 6 6	- - -
Martin (1978)	N = 44 (38, 16 in 2 expts.), Oxford Subject Pool, 18-30 yrs. of age	Digit Span, p. 195 Order recall, p. 195 Immediate Free Recall, p. 195 Delayed Free Recall, pp. 195-196	6 6 6 6	- - -
Paivio (1978)	N = 84 (48, 36 in 2 expts.), introd. psychology students	Pleasantness comparisons, pictures and nouns, p. 201 Monetary value comparisons, pictures and nouns, p. 204	4 4	Space Relations (Form A) of Differential Aptitudes Test Minnesota Paper Form Board (shortened version) Block Visualization Associative Fluency Test (all, p. 201)
Platnick & Richards (1977)	N = 140 introd. Psychol. students, U. Virginia	Word Recognition Threshold, p. 136	1	SAT-V, SAT-M ETS Kit Tests for Word Fluency Memory Span Perceptual Speed Speed of Closure
Richards & Platnick (1974)	N = 80 introd. psychology students, U. Virginia (extreme gps. on SAT-V)	Word Recognition Threshold	1	SAT-V
Robertson-Tchabo & Arenberg (1976)	N = 96 healthy educated men, age 20-80	Single-trial immediate free recall, p. 77 Delayed Free Recall, p. 77 Yes-No Delayed Recognition, p.78 Forward Digit Span, p. 78 Dichotic Digit Pairs, p. 78 Vigilance Reaction Tasks, pp. 78-79	6 6 4 6 1 2	- - -
Rose (1974)	N = 100, mostly undergrad. students, U. Michigan (45 male, 45 female)	Stroop Task, pp. 24-25 Continuous Paired-Associate Memory, pp. 25-27 "Critical" Tracking Task, pp. 27-29 Fitts' Tapping Task, pp. 29-30 Speed-Accuracy Reaction time, pp. 30-32 Word-Recognition Threshold,pp.32-33 Neisser Letter-Search, pp. 33-34 Grammatical Reasoning (A-B), pp. 34-36 Rotated Letters, pp. 36-38	5 6 2 2 2 1 4 4 4	- - -

TABLE 1 (Continued)

Study	Sample	Laboratory tasks	Paradigm	Correlative measures
Rose & Fernandes (1977)	N = 54 female & male students, Georgetown U.	Posner Task, pp. 19b-20 Meyer Task, pp. 20-22 Baron Task, pp. 22-23 Sternberg Task, pp.23-24 Juola Task, pp. 24-26 Clark & Chase Task, pp. 26-27 Collins & Quillian Task, pp. 27-29 Shepard & Teghtsoonian Task, pp. 29-30	4 3 3 4 4 4 3 4	- - -
Snow, Marshalek & Lohman (1976)	N = 25 subjects from study by Chiang & Atkinson (1976) (q.v.)	[See tasks listed for Chiang & Atkinson, 1976]		ETS Kit: Identical Pictures Hidden Figures Card Rotations Paper Folding Surface Development Group Embedded Figures Matching Familiar Figures Raven Progressive Matrices Camouflaged Words Word Transformations Film Tests: STVM I STVM III Film Memory III Sequential Words Successive Perception III
Sternberg, R. (1977)	N = 16 (introd. psychology students, Stanford U., Hi-Lo classifications on Reasoning & Perceptual Speed)	People Piece Analogy Expt., pp. 173 ff. Verbal Analogy Expt., pp. 222 ff. Geometric Analogy Expt., pp. 255 ff.	7 7 7	Reasoning composite Perceptual Speed composite Spatial Visualization Tests Vocabulary Lorge-Thorndike Analogies (See pp. 175, 256)
Thomas, Fozard, & Waugh (1977)	N = 60 males, in 5 age groups, 25-74 yrs., volunteers in Aging Study	Naming Pictures, p. 502 Naming Matching/Non-Matching Pictures, p. 504	5 5	Verbal IQ (Ammons & Ammons, 1962)
Underwood, Boruch, & Malmi (1978)	N = 200 students at Northwestern U., not psychol. majors, not taking introd. psychology	Free Recall series, pp. 399-401 Paired-Associate series, pp. 401-402 Serial Learning series, p. 402 Verbal Discrimination series, pp. 402-403 Running Recognition, p. 403 Situational Frequency, p. 404 List Differentiation, p. 404 Memory Span series, p. 405 Interference Susceptibility, p. 405 Simultaneous Tasks, p. 406 Background Frequency, p. 407	6 6 6 6 4 4 6 6 6 6 & 4 4	SAT-V, SAT-M Vocabulary Spelling
Whitely (1977)	N = 71 h.s. seniors	Short-term Retention, p.468 Relationship Eduction, p. 468 Relationship Evaluation, p. 468 Relationship Choice, p. 469 Response Decision/Execution, p. 469 Choice Reaction, p. 470 Relationship Study & Analogy Completion After Study, p. 470	6 5 7 7 4 2 7	Lorge-Thorndike Intelligence Test Differential Aptitude Test (See p. 467)
Wingfield (1968)	N = 28 univ. undergrads. & grads. (16, 12 in 2 expts.)	Visual Duration Threshold, Pictures, p. 227 Picture Naming, p. 227 Name-Picture Matching, p. 230 Picture-Picture Matching, p. 230	1 5 4 4	- - -

It is noteworthy that tasks in some of the paradigms received little attention, while other kinds of tasks have been much more often studied. For example, the lexical decision task (classified in Paradigm 3) has received very little study from an ID standpoint, while Posner and Sternberg tasks (classified under Paradigm 4) have appeared very often in the studies.

The list of studies surveyed includes a few that present little or no information about IDs, but that illustrate certain aspects of experimental design or task performance that need to be discussed. It is believed, in any case, that the list includes all or most of the more important studies of IDs in ECTs that appeared up to about the middle of the year 1979 and that include data on "adult" (high-school level and above) performances. (Developmental studies involving only younger children have been excluded from consideration here.)

Factor-Analytic Studies of ECT Data

In attempting to analyze the information contained in the studies listed in Table 1, it early became evident that it would be highly desirable to have available information on the dimensions of IDs in ECTs that might be disclosed by factor-analytic procedures. Some of the studies listed include factor analyses of their data; others present correlational data that can be regarded as reasonable to subject to factor analysis. Most of the factor analyses included in the studies were suspect or deficient in one or more respects. Among the more frequent deficiencies were the following:

--There was little deliberate attempt to design sets of variables that could reasonably be expected to produce clear simple structure and/or test hypotheses about factors.

--The variables included in the factor analysis exhibited too much overlap and experimental dependence on each other.

--The analysis used only principal component techniques (analysis of total variance), where a principal factor procedure (analysis of only common factor variance) would have been preferable.

--The data were either under- or over-factorized, in that there was slavish dependence on the Guttman-Kaiser rule that the number of factors analyzed be taken as equal to the number of eigenvalues in a principal component solution that are equal to or greater than unity.

--The factors were rotated, if at all, only orthogonally, usually by Kaiser's (1958) Varimax procedure, whereas the structure of the data may have suggested that the results could be clarified by the use of oblique rotations.

Given the nature of the data available, it was decided to analyze or re-analyze them, wherever possible, by a uniform set of factor-analytic procedures. These analyses generally started, wherever possible, from published correlation matrices, otherwise from published orthogonal factor matrices.

Following is a summary of the assumptions made and the procedures used to perform the analyses or reanalyses of data:

1. It had to be assumed that the published correlation or factor matrices were accurate (at least to the two decimal places generally used in the starting matrices).

2. Where the analysis started with a correlation matrix, it was frequently necessary to eliminate some variables because of excessive overlap and experimental dependence. In general, "raw" variables were preferred over derived variables such as differences. Even so, some experimental dependence was accepted, e.g., in cases where both intercept and slope variables were available but were not highly correlated.

3. As far as was feasible on the basis of information given, all variables were studied in their "positive" orientation; that is, correlations or sets of factor loadings for a variable were sign-reflected in such a way that a positive correlation would indicate that superior performance in one variable (relatively more correct performance, faster performance, etc.) was associated with superior performance in the other. This was done in order to assess the degree to which positive manifold (Thurstone, 1947, pp. 341 ff.) was attained in the analysis. (Generally, it was well attained.)

4. Correlation matrices were subjected to principal component analysis to determine the number of eigenvalues (n) equal to or greater than one, followed usually by several principal factor (or "principal axis") analyses with different numbers of factors (n ± about 2) assumed for determining communalities iteratively. (Generally, the "PA2" procedure incorporated in the SPSS factor analysis program was used for this purpose; see Nie, Hull, Jenkins, Steinbrenner, & Bent, 1975.) The final number of factors accepted for further analysis could be less than, equal to, or greater than the number of greater-than-unity eigenvalues in the principal component analysis, depending on various considerations (the communalities attained, the completeness with which the apparent common factor variance was accounted for, the structure attained in pilot graphical rotations of the data, etc.).

5. On acceptance of a particular number of factors, the resulting Varimax matrix was subjected to graphical, oblique rotations to define the "bounding hyperplanes" (Thurstone, 1947) of the factors as tightly as possible, giving preference, however, to rotations that would tend toward orthogonality of factors. These rotations were generally made "blindly," i.e. without reference to the nature of the variables. From a computational point of view, the rotations generally manipulated transformations of the original unrotated factor matrix so that assessments could be made of how the original factor variance was allocated by the rotations. Usually, the graphical rotations served merely to confirm the general pattern established by the Varimax procedure, but produced factor intercorrelations departing somewhat from zero (usually in a positive direction) and exhibited clearer and more convincing simple structure. In some cases, however, the graphical rotations dictated a fairly radical departure from the Varimax solution, especially when the Varimax pattern established a factor containing a number of variables that from the graphical rotations appeared to be factorially complex. (The writer places more trust in graphical procedures than in any of the analytical oblique procedures, including his own "oblimin" procedure.)

6. In some cases where reports included data on performance on two or three different occasions ("Day 1, Day 2," etc.; see Allen, Rose, & Kramer, 1978; Rose, 1974; Rose & Fernandes, 1977), a "Procrustean" reanalysis was made by averaging the results of the separate graphical solutions and using that average as a "target" for rotating the data from the several occasions. The Procrustes solutions were done by Tucker's "semi-analytical" rotation procedure (Tucker, 1944). (In general the separate graphical solutions for different occasions were remarkably similar even before Procrustean rotation further increased the similarity.)

7. The final results of each factor solution were organized into tables arranged according to the factors and the variables on which they had their highest loadings. These tables, which also show transformation matrices and factor intercorrelations for the oblique solutions, are given in Appendix A.

8. The factors from the different data sets were interpreted, classified, and cross-identified; the results of this cross-identification are discussed below and are utilized in the survey of IDs in ECTs given in this chapter.

We must admit to some misgivings about the factor analyses done here because they are in most cases done on very limited and defective data--with small sample sizes and small numbers of variables that are poorly selected from the standpoint of factor-analytic design. Further, time has not permitted the extensive use of some of the more advanced types of factor analysis, whereby certain problems arising in the present analyses, such as excessively high communalities, might have been avoided. Nevertheless, some consistent and meaningful patterns of findings emerge and if the reader is fully mindful of the limitations of the data the results may still suggest certain tentative conclusions about dimensions of IDs in ECTs.

Table 2 gives a list of the studies and data sets that were employed in studying the factor-analytic structure of IDs in ECTs; it gives details of data sources, procedures, problems encountered, and the like. Each study has been given a code-name that will be used in the discussion below, and all rotated factors are given arbitrary designations with capital letters of the alphabet (A, B, C, etc.). The detailed

TABLE 2

DETAILS OF 30 DATA SETS YIELDING FACTOR-ANALYTIC INFORMATION ON IDs IN ECTs*

Code Name	Study and Source of Data	Number of Variables		Number of PC Eigenvalues		Type of Analysis; Remarks
		(a)	(b)	(c)	(d)	
ALRK	Allen, Rose, & Kramer (1978) Day 1: Day 2: Table 6, p. 63	59 59	14 14	5 6	6 6	PF analysis of selected variables in published R matrix; oblique graphical rotation followed by a Procrustean rotation over Day 1 & Day 2; some variables were averages over Day 1 and Day 2 but inserted in respective Day 1 and Day 2 matrices
BRGR	Berger (1977): Tables 6 & 7, pp. 70-71	NA	9	2	3	PF analysis of variables assembled from her tables of correlations; oblique graphical rotation
CHAT	Chiang & Atkinson (1976) Table 4, p. 667	8	8	4	4	PC analysis of published R matrix; PF not possible because R singular, not iterable
CORB	Cory, Rimland, & Bryson (1977) Table 3, p. 108	26	26	7	8	PF analysis of R matrix supplied; oblique graphical rotations
EGAN	Egan (1978) Table 3	13	13	3?	3	Oblique graphical rotation of published PC Varimax
FERO	Fernandes & Rose (1978) Day 1: Table 9A, p. 39 Day 2: Table 9B, p. 40	19 19	6 6	2 1	2 2	PF analysis of selected variables; oblique graphical rotations
FRDB	Frederiksen (1978) Table 4, p. 17	11	NA	NA	5	Published maximum likelihood F. A.; Jöreskog test used by author to test fit of hypothesized structure
HUFL	Hunt, Frost, & Lunneborg (1973) Table 6, pp. 111-112	15	13	5	5	PF analysis of selected variables in published R matrix; R was singular
HULL	Hunt, Lunneborg, & Lewis (1975) Table 9, p. 222	34	NA	5?	5	Published PC analysis with Varimax rotation; no further rotations made
HUSC	Hussy & Scheller (1976) Table 2, p. 615	40	NA	8	6	Published F.A. by Tryon-Bailey "key-clustering" method; "Inner structure" of 6 clusters extracted from 8 PC factors
JAMA	Jackson & McClelland (1979) Table 4, p. 159 (N = 52)	9	9	2	2	PF analysis of published R matrix; oblique graphical rotation
JAMB	Jackson & McClelland (1979) Table 5, p. 167 (N = 24, subset of above)	16	16	4	4	PF analysis of published R matrix; oblique graphical rotation
JENS	Jensen (1979); R matrix supplied by Jensen (personal communication)	13	13	6	3	PF analysis of R matrix supplied; no rotations beyond Varimax found necessary
LANA	Lansman (1978) Table 4, p. 56	9	7	3	3	PF analysis of 7 variables in published R matrix; no rotations beyond Varimax found necessary
LANB	Lansman (1978) Table 6, p. 72	12	12	3	3	PF analysis of published R matrix; oblique graphical rotation
LUNA	Lunneborg (1977) Study 1 Table 2, p. 314	14	9	2	3	PF analysis of 9 variables in published R matrix; oblique graphical rotations
LUNB	Lunneborg (1977) Study 2 Table 5, p. 322	9	NA	?	4	Published PC & Varimax solution; only loadings $\geq$ .40 reported
MAUC	Malmi, Underwood, & Carroll (1979) Table 3, p. 123	12	12	1	2	Published PF & oblique graphical solution performed by the writer; $r_{AB} = .85$
ROBA	Robertson-Tchabo & Arenberg (1976) Table 3, p. 82	13	13	4	5	PF reanalysis of published R matrix; oblique graphical rotations

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*See Key at foot of following page.

Table 2 (Continued)

		Number of Variables		Number of PC Eigenvalues		
Code Name	Study and Source of Data	(a)	(b)	(c)	(d)	Type of Analysis; Remarks
ROSE	Rose (1974)					
	Day 1: Table 5A, p. 62	18	13	6	5	PF reanalysis of selected variables in published R matrix; oblique graphical rotations followed by Procrustean rotations over Day 1, Day 2, Day 3
	Day 2: Table 5B, p. 63	18	13	5	5	
	Day 3: Table 5C, p. 64	18	13	5	5	
ROFE	Rose & Fernandes (1977)					
	Day 1: Table 11A, p. 70	40	25	7	7	PF analysis of selected variables in published R matrix; oblique graphical rotations followed by Procrustean rotations over Day 1, Day 2
	Day 2: Table 11B, p. 71	40	25	7	7	
SNML	Snow, Marshalek, & Lohman (1976) Table 7, p. 18	24	14	6	6	PF analysis of selected variables in published R matrix; oblique graphical & Procrustean rotations
UNBM	Underwood, Boruch, & Malmi (1978) Table 4, p. 412	22	22	5	5	Oblique graphical rotations of published maximum likelihood and Varimax solution; also a Schmid-Leiman orthogonalization with a general memory factor
WHIA	Whitely (1977) Table 2, p. 471	9	NA	3	3	Published PF & Varimax solution
WHIB	Whitely (1977) Table 3, p. 472	6	NA	2	2	Published PF & Varimax solution

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*Key: Abbreviations used:
R : Correlation (Matrix)
F.A. : Factor Analysis
PC : Principal Component (analysis of total variance)
PF : Principal Factor (Iteration for Communalities)
NA : Not applicable

Column headings:
(a) : Number of variables available in data source
(b) : Number of variables used in analysis or reanalysis
(c) : Number of PC Eigenvalues greater than unity
(d) : Number of factors used in analysis or rotation

results, as already noted, are shown in tables in Appendix A. In classifying the factors found, the paradigms and processes described in the previous chapter are used as a guide.

The Use of Factor Analysis in Studying Cognitive Processes

The present writer (Carroll, 1978a), like others (e.g., Sternberg, 1977, pp. 29-34), has raised questions about the utility of factor analysis and other correlational methods in studying cognitive processes. Aside from the methodological difficulties inherent in factor analysis (indeterminacy, etc.), which must be assumed to have been solved as well as feasible and possible in the factor analyses that are presented here, there is a problem of circularity, stemming from the temptation to assume that simply because one identifies a factor, one has also identified a cognitive process. Variance that generates factors can arise from sources other than processes; for example, it can reflect the fact that two kinds of performances have been learned or practiced together. Nevertheless, the finding that the individual differences on two tasks do not correlate, and appear on different factors, would seem to indicate that the two tasks may involve processes that are somewhat different, if not entirely so. For if the processes were the same, one would expect that variables affected by these processes would appear on the same underlying factor. Inferring that two uncorrelated tasks indicate different processes is more convincing, if the content and stimulus modalities of the two tasks appear not to be different. Factor analysis, therefore, should aid in the classification of processes. This consideration will be appealed to in interpreting the data from our factor analysis work.

Factors of IDs in ECTs

Factors in Task Variables Obtained under Paradigm 1 (Perceptual Apprehension)

Tasks of this type were rather infrequently studied in the available reports, and only two factors can be clearly identified. The first of these appears to be associated with the perceptual apprehension process APSTIM, while the other appears to be associated with the perceptual integration process CLOZR.

The Visual Threshold factor. This is factor JAMB-D from our analysis of Jackson and McClelland's (1979, p. 167) Table 5. (Hereafter, the reader is enjoined to refer to Table 2 for this type of detail.) It arises from the correlation of .37 between two variables, *Single letter threshold* and *Peripheral letter span*, which had loadings of .64 and .46, respectively, on this factor. It appears to represent the amount of stimulus information (with respect to duration of exposure) needed by an individual to identify an alphabetic character. Jackson and McClelland (p. 170) regard these variables as measures of "visual sensory processes" that show no relation to reading ability.

One would have expected measures of word recognition threshold to load on this factor, but Jackson and McClelland did not include such measures in their study. Also, if Frederiksen (1978) had separately analyzed the RTs in his Bigram Identification and Letter Matching tasks, they might have constituted a further Visual Threshold factor. Rose (1974) included a Word Recognition task in his study, but since there was no other task that would tap a visual threshold factor, it did not appear on any such factor. Instead, it appeared (consistently over Days 1, 2, and 3) with weak *negative* loadings on a factor ROSE-B that (below, p. 90) we interpret (very tentatively) as a Fine Motor Hand Control factor.

The Perceptual Closure factor. A Speed of Closure factor has been amply documented from analyses of psychometric tests (see Ekstrom, French, & Harman, 1979, pp. 11-13). In the studies analyzed here, it appears exclusively in psychometric tests, most notably in factor CORB-E, which has loadings on the (mainly) group paper-and-pencil tests Gestalt Completion, Concealed Words, Hidden Patterns, and Drift Direction. One may assume that the common element in these tests is the speed with which the subject can perceptually integrate a stimulus in order to identify it or make a judgment about it. It would be desirable, however, to subject these tasks to detailed and controlled laboratory studies.

Two factors arising in the study by Snow, Marshalek, and Lohman (1976) may be of relevance here: factors SNML-E and SNML-F. Factor SNML-E has its highest loading on a factor composite that the authors themselves identify as "perceptual integration" but loadings also occur on a factor composite identified as "short-term visual memory" and on rate of completing the Raven Matrix test. The status of factor SNML-F is very unclear, since it has a high loading only on a composite, "F3," that arises from negative correlations of their tests Identical Pictures with Successive Perception III and Sequential Words (p. 13). Because of the small sample size (N = 24), the evidence probably does not merit much attention.

Factors in Task Variables Obtained under Paradigm 2 (Reaction and Movement Time)

Tentatively, five factors in the domain defined by Paradigm 2 are posited. All have to do with speed or control of movements made by subjects in reaction time tasks. Since no study included measurements of all of them, one cannot tell whether further study would result in any coalescing of these factors. Several of them, however, appear to be distinct because of their joint occurrence in certain studies: JENS-A vs. JENS-C; ROSE-B vs. ROSE-C; and ROBA-A vs. ROBA-B (a particularly interesting case because the study spreads out several variables between two factors).

Hand movement speed, not under stimulus control. Reasonably clear in its interpretation is factor JENS-C, with high loadings on variance of movement time (experimentally independent of decision time), simple RT, and mean movement time, in a reaction time task designed to investigate decision and movement times separately as a function of number of bits of information processing (i.e., as a function of the number of alternatives in a choice reaction). The factor is orthogonal to JENS-A, which is interpreted as speed of complex information processing (see p. 91 below). Factor JENS-C is characterized as being "not under stimulus control" because the movements involved can occur after decisions that respond to stimuli, and even quite independently of responses to stimuli as a function of the individual's drive, set, or "personal tempo." Possibly similar to JENS-C is WHIA-B, with loadings on measures of response execution and control times that are taken regardless of accuracy; in effect, the subject was given the answers to problems and asked to mark those answers so that the time for response execution could be observed.

Fine motor hand control. Factor ROSE-B is tentatively interpreted as fine motor control because of the consistent loadings (over 3 days) of the slope function derived from a "tapping" task inspired by the work of Fitts (1954). In Rose's version, the subject is required to move the hand rapidly from left to right to make pencil marks in increasingly smaller circles. The slope function is a measure of how well the subject can control these movements as the circles become smaller. Mean performance on a "letter search" task also has loadings on the factor, but this is possibly because that task also requires fine movement control in handling a pencil to make the responses. A "control" tapping (pencil-marking) task measuring mere speed of movement does not consistently load on the factor, a result that seems to indicate that fine motor control of directed hand movements is critical in defining the factor.

Simple reaction time. The clearest example of this factor is found as factor ROBA-A, identified as reaction time to simple events. It has its highest loadings on measures of reaction time to the onset of a single event (the occurrence of a zero) in an auditory vigilance task in which a series of numbers is heard. The loadings decrease as the task becomes more complex, i.e., with the subject being required to make "choice" reactions to any of a specified set of digits, or to the occurrence of any even or odd digit. A simple reaction time measure also loads on factor ROSE-C, but is accompanied by loadings on a "critical tracking" task that might call fast reaction time into play, and on mean performance on a Rotated Letters task. This may also be the same factor as LANA-A, Probe RT during another task (Continuous Paired Associate Learning), although in this case the RT under a control condition--most similar to other simple reaction time tasks--has a lower loading than when the probe comes during an "easy" or a "hard" recall condition during the Continuous Paired Associate task. It may also be identical to the Hand movement speed factor JENS-C mentioned above.

Reaction time to complex sequential events. This is represented by factor ROBA-B, which turned up in our reanalysis of Robertson-Tchabo and Arenberg's (1976) data (it was not identified in their factor analysis because of underfactoring). The loadings on this factor increase as the task becomes more complex: The highest loading is for the reaction time to any contiguous even (or odd) digit as a series of digits is heard at the rate of one per second; correspondingly, the loadings on ROBA-A decrease. Whether the vigilance and auditory aspects of the stimulus series are critical in this factor cannot be assessed from Robertson-Tchabo and Arenberg's data because they did not include in their study more conventional procedures of conducting RT tasks.

Slope of Choice Reaction Time as a Function of Bits of Information. Closely similar to the previous factor is factor JENS-A, interpreted as speed of complex information processing. Essentially, it has to do with the individual's ability to make a choice reaction with relatively little influence of the added amount of information to be processed when the number of choices increases. As we have mentioned earlier (p. 51), this may reflect a greater degree of attentional span--the greater readiness or set to respond to a large number of alternative stimuli. Jensen (1979) proposed that this ability was related to a "g" factor of intelligence; in our analysis, however, the relation is reflected only by the fact that the score on Raven's Progressive Matrix test has a significant but relatively low loading on this factor. This may be due to the fact that scores on the Raven test to some extent reflect speed of information processing, independent of accuracy; the Raven score has a loading of .49 on factor JENS-A but an almost equally high loading on JENS-B, to be described below (p. 116) as measuring the more traditional type of intellectual accomplishment.

Jensen's data are particularly convincing because his experimental method carefully distinguished decision and movement times and because he systematically varied the number of alternatives over 1, 2, 4, and 8 and computed a slope measure. Choice RT factors, LUNA-A and LUNB-A, from Lunneborg's study (1977) were not derived from a slope measure, the number of alternatives was only two, and decision and movement times were confounded. It is therefore difficult to cross-identify those factors.

There being so many possible factors in this domain, it is difficult to identify any of them with a "cognitive" process; of the processes we have identified, one candidate seems to be the XECUTR or Response Execution process. If the factor Slope of the CRT Function really represents an attentional process rather than a response process, it may correspond to IDs in the process we have identified as ATSTIM, the Attention process.

Factors Arising from Accuracy Measures Obtained Under Paradigm 3 (Evaluation/Decision)

Factor ROBA-C may be identified as *Accuracy of Complex Information Processing in a Vigilance Task*. This task, mentioned earlier as yielding two speed factors ROBA-A and ROBA-B, was that in which the subject heard a series of digits and was asked to make responses under several different instructional sets, some of them making rather complex demands. Factor ROBA-C had loadings on measures of accuracy of response under two of the Choice RT conditions: detecting sequences of contiguous even (or odd) digits, and detecting sequences of even-odd (or odd-even) digits. The factor was relatively independent of either of the speed factors (r = .29 with ROBA-A, .15 with ROBA-B).

Possibly quite different from ROBA-C is LANB-C, identified as *Accuracy in a Sentence Verification Task*, or perhaps in more general terms, *Accuracy of Semantic Information Processing*. It had high loadings under three conditions, the "six-item" condition, a control condition, and a "six-second" condition. The different conditions referred to variations in a "dual task" in which the subject had not only to respond to Clark and Chase (1972) sentence verification items but also remember a series of digits, in a type of digit-span task. It is noteworthy that this accuracy factor was completely independent of the RT factor obtained in the same experimental task (mentioned below, p. 102).

We also note the possibility that factor WHIB-A, having to do with the correctness of analogy evaluations, may be appropriately classified here, in that it involves comprehension of semantic relations.

Factors Arising from Measures Obtained Under Paradigm 4 (Stimulus Matching/Comparison)

The data available for assessing the dimensionality of the IDs observed in this domain are confusing--because of the somewhat conflicting evidence from different studies--, and frustrating--because there are no studies that included the variety of variables that would have been needed to resolve several important questions that may be raised about the number of cross-identifiable factors in the domain and the interpretation of those factors.

Perceptual Speed factors. Well established in the traditional psychometric literature is a Perceptual Speed factor, found in a variety of tests or tasks requiring the rapid comparison of visual patterns--whether in drawings of designs or in series of digits, alphabetic characters, or printed words. However, as pointed out by Ekstrom, French, and Harman (1979, pp. 29-31), the nature of this factor is "less clear than was formerly thought"; there are possibly several types of perceptual speed factors. Unfortunately, the data examined in the present survey contribute little to clarifying our knowledge.

Two factors identified here have a strong resemblance to the traditional Perceptual Speed factor: CORB-C and HULL-B. CORB-C is loaded exclusively with variables of a traditional type: a Clerical Test (.71) operationally used in Naval personnel selection, an experimental but non-computerized test called Counting Numbers (.63), and a computerized test called Comparing Figures (.39). All these tests presumably place a premium on speed in making rapid comparisons of visual details, or in scanning series of stimuli to locate specified targets, although they are generally scored for accuracy as well. (In addition, there is a loading of .32 for Youth, indicating that older subjects are less rapid and/or accurate.) HULL-B has loadings for two traditional clerical speed tests: Clerical speed (names) (.68) and Clerical speed (numbers) (.54). In addition, however, it has loadings on two ECT variables: Name minus physical match time (.61) and Color-name minus Asterisk reading time (.61). The first of these variables is derived from the Posner task, which involves rapid comparison of alphabetic characters; it is a difference score that, according to Hunt's (1978) formulation, indicates the added amount of processing required to retrieve the name of an alphabetic character as opposed to simply recognizing its physical shape. This result is congruent with the notion that Perceptual Speed requires retrieving the names of stimuli such as alphabetic characters or printed digits, although actually the usual perceptual speed test requires only physical shape comparisons. The Color name minus Asterisk reading time is also a difference variable, derived from the Stroop task, that measures the amount of difficulty the individual encounters in reading the names of colors when they are printed in a color other than the name itself. The task does not directly involve comparisons, except possibly in some covert way. The acceptance of this datum is somewhat questionable, however, because of methodological problems in the use of difference variables in factor analysis (Carroll, 1978a).

Possibly to be considered in connection with a Perceptual Speed factor are two factors arising from experimental tasks that are similar to those employed in traditional Perceptual Speed tests: The first of these is ALRK-C, with high loadings, on each of two days, on the intercept and the slope of a function derived from a so-called Scan and Search task in which the subject searches a list of letters for short-term-memorized target letters (1, 2, or 4 letters). The intercept measures, presumably, the subject's reaction time apart from the size of the memory set, while the slope measures the added processing time per letter in the target set. (This is reminiscent of the Slope of Choice Reaction Time factor mentioned earlier, p. 91.) The common factor variance here, however, may be artifactual because of the experimental dependence of the slope and intercept variables. The second factor to be considered is JAMB-C, highly similar to ALRK-C in that it has loadings on mean reaction time (.74) and "slope" (.90) for a Multiple Letter Display task in which the subject searches for a previously presented target letter in a search set of 2, 4, or 6 letters. The study (Jackson & McClelland, 1979) also yielded a factor (JAMB-A) with loadings on a variety of Posner-type tasks; the Multiple Letter Display RT loaded .48 on this, but the Slope did not (.00). The study included no psychometric tests designed to measure

Perceptual Speed, and therefore gives no evidence as to the status of factors JAMB-C or JAMB-A relative to the conventional Perceptual Speed factor. JAMB-C may be a highly specific factor associated with the experimental dependence of the two measures on which it has loadings, but it may also represent "access to overlearned memory codes for visually presented letters" (Jackson & McClelland, 1979, p. 151).

Spatial Speed; Spatial Accuracy. Next to consider are two factors arising from Egan's (1978) factor analyses of speed and accuracy measures of performance on spatial ability tasks. One of these factors is EGAN-B, with high loadings on latency measurements for three experimental versions of spatial ability tests: a block rotation test (.87), a version of the Guilford-Zimmerman Visualization test (.84), and a Spatial Apperception test (.67). These latency measures were based exclusively on correct responses. We interpret it as a Spatial Speed factor. EGAN-A was a factor that had high loadings on a variety of accuracy scores from spatial ability tests; its correlation with factor EGAN-B was essentially zero. The regular score from the Guilford-Zimmerman Perceptual Speed test loaded on both of these factors: .30 on EGAN-A and .42 on EGAN-B. We interpret it as a Spatial Accuracy factor. This result suggests, at least, that speed and accuracy in the spatial ability domain are independent (at least in the sample studied by Egan, which was selected for relatively high spatial ability), and that an ordinary time-limit, number-correct score on a spatial ability test measures both speed and accuracy, as one might expect. Since Egan's study was for the most part limited to spatial ability tests and did not include any Posner-type or Neisser-type tasks, we cannot draw any conclusions from it as to the relation of factors EGAN-A or EGAN-B to factors derived from those types of tasks, a matter to which we will shortly turn. Before doing so, however, we would point out that the kinds of visual comparisons involved in Egan's spatial tasks are much more complex and demanding than those involved in Posner- or Neisser-type tasks; they generally require attention to details of visual patterns, and mental rotation of spatial configurations. On the other hand, the Guilford-Zimmerman Perceptual Speed test, which has apparently significant loadings on both EGAN-A and EGAN-B, does not require mental rotations, but only the matching of drawings; further work needs to be done to explore the possible differentiation of "pure" perceptual speed tasks from "pure" spatial tasks.

Factors involved in Posner-, Neisser-, and Sternberg-type tasks. In Chapter 2, we classified all three of these types of tasks under Paradigm 4, even though some of them make more demands on short-term memory than others, because they all require *comparisons* of external or internal stimuli. The factor-analytic data we have examined yield considerable evidence for such a classification, and thus for the inference that we are dealing here with measures of what we have called the TSTSIM process.

Reviewing this evidence, we tentatively conclude, however, that there are *two* major factors involved in these tasks, at least in the Neisser- and Sternberg-type tasks. (The Neisser-type task is one that typically involves visual search for one or more targets; the Sternberg-type task typically involves search of short-term memory for a single target, but sometimes for more than one target. Thus, the major difference between these tasks consists in whether the set of stimuli in which search occurs is physically present, as in the Neisser-type task, or present only in memory, as in the Sternberg-type tasks. The Posner-type task involves only comparison; it involves no "scanning" of either a visual or a memory search set.)

The first factor we consider to be involved in these tasks is essentially a *Speed of Mental Comparison* factor. In general, it is loaded with reaction time measures from the several variants of the Posner task, and with the *intercept* measure from Neisser- and Sternberg-type tasks. The intercept measure is in effect a "pure" speed of comparison measure that controls for the amount of information to be processed--the latter being measured by the slope variable. Five more or less clear instances of the Speed of Mental Comparison factor were disclosed in our survey of factor-analytic results. Each of these will be discussed.

Factor CHAT-A has extremely high loadings (.98) for the *intercept* measures from Visual Search (Neisser-type) and Memory Search (Sternberg-type) tasks, reflecting the correlation of .968 between these measures ($N = 30$, $p < .01$); correlations with slope measures were reported as non-significant, although in fact the Memory Search Intercept correlated .427 with Visual Search Slope. Unfortunately, the intercept measures contained elements of stimulus encoding, binary decision, and response execution. The study (Chiang & Atkinson, 1976) did not include any measures of simple or choice reaction time, and the experimental procedures failed to separate decision and movement time. (There were similar failures in most of the other studies to be mentioned here.) Factor SNML-C, based on the same data as CHAT-A, may be similarly interpreted.

Factor JAMB-A had loadings on five variants of a Posner-type task: Physical Letter Match (.94), Simple Pattern RT (.93), Name-letter Match (.85), Synonym Match (.79), and Homonym Match (.62). (The last three of these had small but possibly meaningful loadings on JAMB-C, described above, p. 94, possibly reflecting the orthographic and lexicosemantic aspects of these variants--even though factor JAMB-C was not interpreted in these terms.) Jackson and McClelland (1979) regard these variables as indicating speed of accessing overlearned memory codes for visually presented letters.

Factor ROFE-A had loadings on four variables from Posner-type tasks:

	Day 1	Day 2
RT--Physical Match, Same	.43	.60
RT--"Different" (Physical & Name Match combined)	.32	.57
RT--Rule (Vowel/Consonant Category) Match	.33	.53
RT--Name Match, Same	.31	.39

as well as consistently significant loadings on three intercept variables:

	Day 1	Day 2
Sternberg Intercept, Positive	.75	.81
Sternberg Intercept, Negative	.55	.54
Collins & Quillian, Superset Intercept	.47	.55

This study included no measures of "pure" simple or choice reaction time factors and it is thus impossible to say whether this factor would fall together with any such factors.

Factor ALRK-A is slightly less clear. Its "significant" loadings were as follows:

	Day 1	Day 2
Posner Physical Match RT	.78	.87
Set Membership Intercept (Set Membership is essentially a Sternberg-type task)	.78	.76
Letter Rotation-Slope	.54	.25

Why the Letter Rotation Slope (rather than the Intercept) appeared on this factor is unclear, but the results are not entirely consistent over the two days. The Intercept and Slope of the Scan and Search task (a Neisser-type task) had weak and quite inconsistent loadings on the factor. The study (Allen, Rose, & Kramer, 1978) included no measures of "pure" RT factors that would have permitted an assessment of the relation of ALRK-A to such factors.

Finally, factor HULL-E may belong with the others mentioned here; it had loadings on two intercept variables from the Sternberg task (Negative, -.59; Positive, -.56) and the RT from the Posner physical match condition (-.56), but the loadings of two variables derived from the Sperling Iconic Memory task are even higher. Since the Sperling task was used only in this study we can only speculate as to whether it captures something critical in this factor. The investigators state that this factor "appears to be a measure of speed of immediate perception and, possibly motor reaction" (Hunt, Lunneborg, & Lewis, 1975, p. 223).

We now mention four instances of factors that are loaded heavily with slope variables from either Sternberg- or Neisser-type tasks, or both. In every case, these factors contrast with, and are essentially uncorrelated with, the intercept factors that have just been mentioned.

CHAT-B has loadings of .97 and .87, respectively, for the slope variables derived from Visual Search and Memory Search tasks. The correlation between these variables .832, was so high that Snow, Marshalek, and Lohman (1976), in their continued analysis of Chiang and Atkinson's (1976) data, combined them into a single variable, "Average Slope," which came out on their factor SNML-B along with SAT-Verbal and SAT-Quantitative.

ROFE-C features high loadings on two Sternberg-task slopes: Positive (Day 1, .51;

Day 2, .60) and Negative (Day 1, .72; Day 2, .58). Several other variables had somewhat inconsistent loadings on it, as follows:

	Day 1	Day 2
Juola Word, Slope Negative	.26	.46
Clark "Negation"	.39	-.02
Clark "Base"	.22	.52

We cannot interpret these latter results. On both days, ROFE-C had rather high correlations with Factor ROFE-A (the RT + Intercept factor): .46 and .47 respectively.

Factor HULL-C had "significant" loadings for slope variables from the Sternberg task (Positive, .53; Negative, .49), but this factor had higher loadings on a variety of other variables: Dichotic listening, category score (.73), a variable derived from performance on the "Sunday + Tuesday" task (.62), and the Ear-category score from Dichotic listening (.61), results that make this factor difficult to interpret beyond the statement that it may have to do with short-term memory. Hunt, Lunneborg, and Lewis suggest that "this factor is associated with the ability to access and scan information in STM, without imposing the additional requirement that the data located be subjected to a transformation" (1975, p. 223).

In two instances (factors ALRK-F and HULL-C), factors contained high loadings on both slope and intercept of the Sternberg task (though with opposite signs if the raw variables are considered). These factors may arise partly because of the specific overlap variance associated with the experimental dependence of these variables, and partly because there was an insufficient amount of "tying down" of common factor variance in the studies in question to allow the slope and intercept variables to appear on separate factors.

Frederiksen (1978) identified a factor, here called FRDB-A, that he regarded as measuring Graphemic Encoding. Because the measures that loaded on it resemble measures of slopes of visual and memory search, it is mentioned here as possibly relatable to slope factors identified in other investigations. One is reminded that in the last analysis all the measures of the visual/memory search task involve digit or alphabetic symbols, and it appears that subjects differ in their speed of accessing the codes for these symbols.

Although some consistent patterning of results has been demonstrated, important questions that demand further empirical research remain: What relation does the RT and Intercept factor of the Posner-Sternberg-Neisser tasks have with "purer" factors of simple or choice reaction time? What is measured by the Slope factor of these tasks, and can it be measured by still other tasks? In what way are either of these factors related to Perceptual Speed factors? Would either of them fall together with perceptual speed factors in a thoroughgoing and systematic study of the matter? Is the use of digit and alphabetic symbols critical to the definition of these factors?

Until these questions are answered, it is probably pointless to speculate about what cognitive processes are involved in these factors. We note again our recommendation that research utilize experimental procedures that will permit the separation of decision and movement time factors in response execution, in this way possibly producing better defined variables in further factorial studies.

Speed of Semantic Processing. The Rose and Fernandes (1977) study, whose correlational matrices were reanalyzed in our survey, revealed several other factors that probably are to be classified here--i.e., under factors arising from speed measures obtained under Paradigm 4. The most prominent and general of these is factor ROFE-B, which had "significant" loadings on a variety of cognitive task variables, as follows:

	Day 1	Day 2
Baron Task: Sense-Nonsense RT	.66	.82
Baron Task: Sense-Homophone RT	.64	.75
Collins & Quillian: Property Intercept	.53	.74
Baron Task: Homophone-Nonsense	.47	.63
Juola Category, Slope, Positive	.28	.63
Meyer "Word"	.45	.46
Meyer "Non-Word"	.29	.44
Collins & Quillian: Superset, Intercept	.14	.32
Clark & Chase: "Base"	.30	.31

Before discussing the meaning of these results, it should be pointed out that the Day 2 results are much clearer than those of Day 1. Further, on Day 1, the correlation between factor ROFE-B and ROFE-A was .58, as compared to only .18 on Day 2. This might indicate that on Day 1, performance on the above tasks was much more affected by a speed factor that also was implicated in Posner and Sternberg tasks (i.e., the RT and Intercept factor described above), whereas on Day 2 the subjects had acquired a familiarity with the task demands such that this speed factor was less involved. (In most of the tasks, performance improved, on the average, from Day 1 to Day 2.)

Not all the tasks are strictly to be classified under Paradigm 4; in fact we classify the Meyer, Baron, and Collins and Quillian tasks under Paradigm 3. The common element, however, in all of the above tasks is the requirement that the stimuli be evaluated or compared with respect to their orthographic or their semantic aspects. The "Word" and "Non-Word" variables from the Meyer task are speeds of recognizing letter strings as words or non-words in the English language. The variables from the Baron task are speeds of recognizing printed sentences as "sense" or "nonsense" depending upon certain instructional sets. The intercept variables from the Collins and Quillian task are speeds of verifying sentences as "true" or "false," controlling for the amount of presumed information processing associated with different "levels" of set and superset relationships. The Juola Category task required the subject to evaluate whether a probe word was an exemplar of a word in a memory set that might consist of from one to four words; the slope variable would be a measure of the added information processing involved in handling each additional memory set word beyond one. (Why only the slope for positive instances appeared in this factor is unclear; it must be noted, however, that factors ROFE-D, ROFE-E, ROFE-F, and ROFE-G were specific factors that accounted for most of the variance in the slope and intercept measures from the Juola Word and Category tasks, and generally showed marked factor intercorrelations with factor ROFE-B. It would probably be profitable to reanalyze the data, omitting one of each pair of slope and intercept variables on the Juola tasks, but time has not permitted this to be done.) The Clark and Chase "Base" time is (apparently--the report is unclear) a parameter describing the speed of the basic sentence-encoding operation involved in this task.

Closely similar to factor ROFE-A is factor LANB-A, which has loadings on Clark and Chase sentence verification RTs under three conditions, but also on RTs from a three-term series task (and on the University of Washington verbal test).

Of possible relevance here is factor LUNB-B which was represented by two measures of rate in performing the Raven Matrix test, but the Raven test does not involve orthographic or semantic information processing.

Miscellaneous Factors in Variables Obtained Under Paradigm 5
(Naming/Reading/Association)

Few ECTs classifiable under Paradigm 5 were used in the 55 studies in the sample examined here, and even fewer of them appeared in correlation matrices or factor analysis batteries. We have therefore little to report in this category.

Word Retrieval Latency. No study examined used a picture-naming task. Undoubtedly, however, a picture-naming or word retrieval latency factor could be identified through an appropriate design. Carroll (1976b) observed highly reliable individual differences in such latencies, when control was exercised for word frequency and age-of-acquisition of the picture's name (variables found to affect picture-naming latency). He found correlations of .67 to .69 between scores on a psychometric test of picture-naming and mean reciprocal latencies taken under experimental conditions; in multiple regression analysis, only this psychometric variable had a significant regression weight for predicting the experimentally obtained latencies; that is, a variety of other psychometric tests (Hidden Figures, Thing Categories, Controlled Associations, Gestalt Completion, and Advanced Vocabulary) contributed no significant predictive variance beyond the Picture Naming test.

Perceptual Facilitation in Encoding Multiletter Arrays. Factor FRDB-B was interpreted by Frederiksen (1978) as a factor of Perceptual Facilitation in Encoding Multiletter Arrays. It had high loadings on Scanning Speed (rate of scanning a multiletter array, a variable derived from measures of rate of letter-naming of parts of such arrays), Perceptual facilitation (a variable derived from RTs for dissimilar letters vs. similar letters in a Posner Letter Matching task), and Bigram probability (a variable derived from RTs for low probability vs. high probability bigrams in the letter-naming task). It seems to reflect the individual's knowledge and experience with grapheme-phoneme sound correspondences in English orthography, and as such may be related to Baron and Strawson's (1976) contrast between "Phonecians" (people who use orthographic rules in decoding words) and "Chinese" (people who make little use of such rules).

Phonemic Translation; Depth of Processing in Word Recognition. Two other factors derived by Frederiksen (1978) from a model of the reading process deserve mention here: Factor FRDB-C was called Phonemic Translation and was regarded as indicating speed and efficiency in letter decoding in the "early" stages of word perception, being measured by variables in which the length or complexity of letter strings affects speed of response. Factor FRDB-E, interpreted as Depth of Processing in Word Recognition, has to do with the extent to which a subject is able to use a "visual or whole-word recognition strategy in recognizing common words" (p. 16), as opposed to a strategy in which words are decoded "*de novo*," as it were. Various research evidence, not reviewed here (see, e.g., Perfetti & Lesgold, 1979), suggests that both these factors reflect education and experience in reading.

Control of Articulation. Factor LUNB-C was interpreted by Lunneborg (1977) as reflecting "time to respond with more [than minimal] pressure on the system (delay of auditory feedback, overcoming phonetic convention, searching LTM for learned facts)" (p. 322). If it were not for the presence of the intercept of his "verbal problem solving task" on this factor, one might be inclined to interpret it simply as control of articulation--i.e. reading speed under delayed auditory feedback and ability to pronounce words substituting r's for l's and vice versa. The factor has some similarity, from a logical point of view, to Frederiksen's FRDB-D, Automaticity of articulation, which was measured principally by a variable that reflected the amount by which a two-syllable pseudoword slowed down a subject's pronunciation of it as opposed to a one-syllable word.

Stroop Reading task. Factor ROSE-A reflects the specific variance in rate of performing the Stroop task--whether under the Color-naming instructions or the Color-word reading instructions. (The "Stroop difference," i.e. the difference between the color-word naming and the color-naming scores, was not entered into the factor analysis because of the overlap problem; in any case, it did not correlate significantly with any other variable in Rose's study.) At the same time, the factor analysis disclosed that the Stroop variables had consistent, though weak, loadings on another factor, ROSE-D, which remains to be discussed (see p. 117 below). The Stroop variables therefore appear to be factorially complex. Nevertheless, at least for the types of adult populations utilized in Rose's study, there seems to be no advantage in deriving a difference variable. The story may be quite different in the case of children or other groups whose reading skills may not have attained sufficient maturity to make reading of the color words virtually automatic.

Factors Arising from Variables Obtained under Paradigm 6 (Episodic Memory Read-out)

The major sub-domains of factors obtained with tasks classifiable under Paradigm 6 are: Memory Span, Free Recall, Paired Associate Learning, and Verbal Discrimination, but these domains appear to overlap to a considerable extent.

Memory Span factors. A number of instances of Memory Span factors were identified, as might be expected from the fact that Memory Span (or "Span Memory") has been regarded as a well-established factor in the psychometric literature, even though not completely well understood (Ekstrom, French, & Harman, 1979, pp. 24-26). The data examined in our survey of recent studies made some contribution to the understanding of Span Memory abilities.

Factors CHAT-C, SNML-D, LANA-C, LANB-B, and UNMB-C, may all be regarded as "standard" memory span factors. All had substantial or high loadings for immediate digit span or similar tasks, scored for number of items correctly recalled or for threshold of failure to recall a set. Of some note is the fact that both CHAT-C and LANA-C also had moderate loadings for a verbal aptitude composite. LANB-B had slightly higher loadings for digit-recall tasks when they were conducted in conjunction with another task (continuous paired-associate learning). In the case of UNMB-C, the highest loading was obtained for a letter-recall task in which the letters had low phonetic similarity; the loading for a letter-recall task with letters of high phonetic similarity (e.g., B, C, D, G, E) was lower. This appears to indicate that phonetic similarity only contributes unwanted error variance in a memory span task, and does not contribute to the measurement of individual differences in memory span. The factors contained both auditory and visual memory span tasks; as far as the measurement of individual differences is concerned, it does not appear to make any difference whether visual or auditory stimuli are used (Jensen, 1971).

Several factors were apparently not "pure" memory span factors, but are in any case classified here: FERO-B had, on both Day 1 and Day 2, its highest loading on a letter memory span task (with low-similarity letters), but at least on Day 2 it also had high loadings for a running recognition task, a situational frequency task (remembering which list a word had occurred in), and an "interference susceptibility" task (a paired-associate task in which the pairings change over trials). (This factor is somewhat similar to factor UNMB-D, described on p. 110 below.)

Factor HUFL-A had its highest loading for a measure of clustering in a blocked free recall task, but loadings of .80 for a digit span task with stimuli given at the rate of one every 6 seconds, and .62 for a digit span task with stimuli at the rate of one per second (the more usual rate). It also had loadings of .54 for number correct in a CVC free recall task, and .49 for the α-parameter of the Atkinson-Shiffrin continuous paired-associate task, thought to measure the probability of an item entering short-term memory.

Possibly factor HULL-D may be interpreted as a type of (delayed) memory span factor; it had loadings on several variables derived from a Peterson-Peterson-type task which concerned the subject's ability to retain order information in letter sequences, presentation of which was followed by an interfering task. (Compare factor BRGR-A below.)

Factor ALRK-B was a specific memory span factor that arose because of the (possibly unwise) use of both the slope and the intercept variables in our factor analysis. These variables, in their raw form, had an intercorrelation of -.81. Inspection of the correlation matrix indicates that neither of these variables had any significant correlations with any of the other variables in the matrix, except (very moderately) with certain variables in a Mental Addition task that was supposed to tap aspects of short-term memory.

A most interesting and relevant study in this domain was that of Berger (1977). Data from her correlation matrices were assembled in order to make a factor analysis of nine of the variables she used--seven of these being types of memory span tasks. The eighth and ninth were scores on two tests regarded as measuring field independence, Embedded Figures and the Rod and Frame test. The correlation between these tests was .60. Berger's study was a follow-up to one by Jensen (1964), who had identified two factors in the memory span tasks: a "Registration" factor measured principally by immediate memory span tests and an "Interference" factor measured principally by delayed digit span tests. In our analysis, three factors emerged, with the following loadings on oblique factors:

		A	B	C	h^2
BRGR-A					
3 Delayed Digit Span 2-9		.83	.20	-.06	.78
9 Embedded Figures Test		.77	.17	-.09	.65
8 Rod and Frame Test		.77	.00	-.03	.62
1 Long Digit Span		.75	.25	-.04	.69
2 Retroactive Inhibition		.72	.30	.06	.74
6 Delayed Digit Span 4-7		.66	.02	.41	.86
BRGR-B					
7 Immediate Digit Span 2-9		.15	.76	.00	.67
4 Immediate Digit Span 4-7		.01	.67	.30	.70
BRGR-C					
5 Proactive Inhibition		-.02	-.01	.59	.39
Factor correlations:	A	1.00	.08	.28	
	B	.08	1.00	.27	
	C	.28	.27	1.00	

All the digit span tests were of a standard type, with digits being presented auditorily at the rate of one per second. They were administered in groups, however, such that various types of delayed recall could be observed. The Retroactive Inhibition score was for cued recall of a given list after being presented with a second list. The Proactive Inhibition score was for cued recall of the second list after being presented with two lists. The "delayed" recall was recall after being required to echo a random series of the words "plus" and "minus" for 10 seconds after list presentation. Subjects were informed of the recall condition only after presentation of a list.

The results suggest that immediate digit span ability (Factor B) is quite independent of ability to recall digit lists after delays, with or without interference (Factor A). A third ability (Factor C) is that of being able to resist the effects of proactive inhibition. What is of most interest is the fact that Factor A is highly related to field independence as measured by either the Embedded Figures test or the Rod and Frame test. It was also highly related to scores on an "Attention Test"--actually a questionnaire having to do with feelings of boredom, ability to maintain attention during difficult tasks (lectures, etc.) (Singer & Antrobus, 1963). Tasks loaded on Factor A, therefore, might be more relevant to appraising learning ability than the usual type of immediate memory span test.

Free Recall factors. Several clear instances of a Free Recall factor appeared in the survey. Clearest and best supported (because of the variety of tests and the large N of 200) was factor UNBM-A, with loadings on several types of free recall tasks involving the presentation of word lists and requiring subjects to recall as many words as possible in these lists, regardless of order. Some of the tasks loading on this factor involved recall of pairs of associated words, or of categorized lists. The investigators had hoped that certain attributes of the material to be memorized or learned would affect the factor structure, but this turned out not to be the case. Apparently, the ability to register material in memory for later recall does not ordinarily interact with the nature of the material (although one can conceive extreme cases in which it would, e.g., cases in which material in two languages would be memorized by monolingual speakers of the two languages.) A somewhat similar factor is MAUC-A, containing a number of variables in which the kinds of material to be recalled were varied in complexity (i.e., words vs. groups of words vs. short sentences). Again, the complexity of the material did not seem to affect the factor structure in any major way. Some serial learning variables were included on this factor, which was highly correlated (r = .85) with factor MAUC-B (a Paired Associate factor).

Other clear Free Recall factors were CORB-F, which was loaded with variables measuring recall or recognition of pictured objects or words (but not patterns), and FERO-A, most consistently loaded with a free recall measure and a measure of the ability to recall which of several lists an item had appeared in. Cory, Rimland, and Bryson interpreted their orthogonal version of factor CORB-F (their factor 3) as representing a short-term memory ability emphasizing "the direct recall of stimuli having high associational value or substantial verbal mediation" in contrast to their version of factor CORB-D (their factor 7), which they interpreted as requiring primarily "rote reproduction" of stimuli "with little if any associational content" (1977, p. 108).

Factors that were less clearly identifiable as free recall factors were ALRK-D, HUFL-D, HUFL-E, HUFL-B, ROBA-B, and ROBA-E. The lack of clarity was probably due, in most of these cases, to small Ns and inadequate variety of variables in the analysis. ALRK-D was most highly loaded with a sentence recognition task and a clustering score from a sentence recall task. In the case of HUFL-D a measure of correctness of CVC recall was associated not only with a measure of free recall of words blocked by categories, but also with two parameters arising from the Continuous Paired Associate task: r (STM buffer size) and θ (the rate of transfer to Intermediate Term Memory). Relatively independent of this (r = .41) was factor HUFL-E with its chief loadings on two other parameters of the Continuous Paired Associate task: τ, the measure of rate of loss from Intermediate Term Memory, and α, the probability that an item will enter Short-Term Memory. The study yielded yet another factor, HUFL-B, loaded principally with a measure of recall of unblocked words and the intercept of the Sternberg memory scan task. The study by Hunt, Frost, and Lunneborg (1973) was frankly exploratory and these results were not intended to be more than suggestive. They are, however, worth following up with more ambitious designs and a larger number of variables.

The factors ROBA-D and ROBA-E may be interpreted, after the authors (Robertson-Tchabo & Arenberg, 1976), as referring respectively to "Secondary Memory" and "Primary Memory." The first of these was loaded chiefly with a measure of correct free recall of items in the first seven positions of 12-item lists, along with loadings for delayed free recall. Thus, it appeared to tap memory for more remote memories (the "primacy effect"). In contrast, factor ROBA-E was loaded almost exclusively with a measure of recall for the last five positions of a list, corresponding to what is often referred to as the "recency" effect. It may be highly similar to Berger's immediate memory or "registration" factor BRGR-B.

Paired-Associate Memory factors. The Associative Memory factor is well recognized in the psychometric literature (Ekstrom, French, & Harman, 1979, pp. 22-24), and at least two instances of such a factor appeared in the present survey. The clearest was factor UNBM-B, showing associations with a variety of paired-associate learning tasks, as well as several serial learning tasks. This factor was highly correlated (r = .62) with factor UNMB-A according to our oblique graphical rotation results. Similarly, factor MAUC-B identified a variety of paired-associate variables but was highly correlated (r = .85) with factor MAUC-A, a free recall factor. In each of the studies in which these factors were disclosed, serial learning tasks tended to be complex, having loadings on both free-recall and paired-associate factors, a finding which makes sense in view of the notion that serial learning involves registration and storage of both the items to be learned and the order information or associations between successive pairs of items. Yet, serial learning is not the same as memory span, possibly because serial learning is commonly done over a series of trials.

Factor LANA-B was loaded with two variables arising from performance in a Continuous Paired-Associate task: one under a "hard recall" condition and one under an "easy recall" condition. It was also loaded (.41) with the Probe RT in the easy recall condition, suggesting that in the easy recall condition there was some spare capacity for responding to the probe stimulus beyond what was permitted by IDs in factor LANA-A (a reaction time factor discussed on p. 90 above).

We have already mentioned the factors HUFL-D and HUFL-E that contained loadings for parameters of performance on the Continuous Paired Associate task, pointing out only that this work needs to be followed up.

A Verbal Discrimination factor. Factor UNBM-E was loaded almost exclusively with two measures from verbal discrimination tasks. These are tasks in which the subject has to learn, over a series of trials, which one of a series of pairs of stimuli is to be selected or responded to as the "correct" choice. It also had loadings on one free-recall variable (.42 on FR-S, "spaced and massed") and the List Differentiation variable; why such loadings occurred is not clear (but see further discussion below). Also, it is not clear why this factor should not fall together with the Paired-Associate factor since what the subject has to learn is essentially associations. Nevertheless, these are passive, "recognition" associations rather than active, "recall" associations. Perhaps one should look to the large literature on verbal discrimination to find an explanation of the nature of this factor.

A further memory factor. Factor UNMB-D does not seem to correspond to any factors identified previously, either in the psychometric literature or in our survey. The investigators remarked simply that it was "most clearly identified with recognition and frequency discrimination" but "did not escape loadings of some magnitude from many of the other tasks" (Underwood, Boruch, & Malmi, 1978, p. 413). It was loaded most heavily with a judgment of situational frequency, a basic measure of running recognition, and a measure of ability to recognize pairs encountered in a complex "simultaneous acquisition" task. It may be suggested that it deals with memories of relatively complex events, particularly in view of its loadings on several of the more complex free-recall tasks (abstract words, pairs of associates, and categorized lists); however, see further comment below.

Correlations of memory factors. The oblique rotations that were performed for most of the data sets in this survey gave rise to factor correlation matrices that in some cases deserve serious attention. This was especially true for data set UNBM, because the large N (200) could be expected to produce substantial reliability in the factor correlations. A single second-order factor accounted for nearly all the common variance in the matrix of factor correlations, with the following loadings:

UNBM-A (free recall)	.726
UNBM-B (paired-associates)	.833
UNBM-C (memory span)	.245
UNBM-D (complex events?)	.459
UNBM-E (verbal discrimination)	.369

Using these results, the oblique factor loading matrix was orthogonalized by the Schmid and Leiman (1957) procedure; the resulting orthogonal matrix is given in the Appendix along with the oblique factor matrix. These results suggest that there is a general memory factor ("GM") in all the memory tasks studied by Underwood, Boruch, and Malmi (1979), strongest in the paired-associate tasks, nearly as strong in the free-recall tasks, and considerably weaker in the remaining tasks.

The general memory factor is probably not to be interpreted as related at all strongly to the "g" factor of intelligence as commonly conceived. In fact, examining correlations in Underwood et al.'s (1979) Table 3 we find generally low correlations between memory task scores and scores on Vocabulary, Spelling, and SAT-V and SAT-M--all of which would be expected to reflect "g" to a considerable extent. Rather, we interpret the general memory factor as one that reflects an individual's ability to register, store, and retrieve any kind of material in episodic memory. Underwood et al. would probably be inclined to regard it as an ability to form associations, since they comment on how "associational ability" appeared to "swamp" any tendency of subjects to be responsive to attributes of particular tasks, but we believe the factor is even broader than this, because memory for an event of any kind does not seem to be necessarily dependent on forming any association with some other event, or with a previous representation in memory. Further research is needed to establish the connection of the general memory factor with other factors of IDs in ECTs.

Detailed study of the orthogonalized matrix can pay attention to the exact size of the loadings because they can be interpreted as correlations between the task variables and the respective factors. In view of the N of 200, a loading of .14 or greater can be taken to be significant ($p < .05$). Some of the tasks are significantly complex, having what might be called "anomalous" loadings on factors other than the one which their highest loadings contribute to defining. These anomalous loadings give interesting insights into the nature of the factors and the tasks.

The single anomalous loading (.142) on the free-recall factor UNBM-A is for variable 9, Paired Associates--Control, suggesting that one strategy in paired-associate learning that can be adopted by at least some subjects is to learn items in terms of rote sequences like those that are the content of free-recall tasks. (A paired-associate item can be treated as a two-item free-recall list.) When a test or variable is factorially complex, two types of possibilities can be considered. First, the complexity may result from an inherent property of the task whereby successful performance calls on at least two abilities in combination, as indicated by the factor loadings. Second, the two or more factor loadings may arise because different strategies are used by different groups of subjects; in the averaging process that occurs in summarizing data by correlational and factor-analytic procedures, these different strategies show up as a set of significant loadings on two or more factors.

There were no "anomalous" loadings on the paired-associate factor UNBM-B; this may indicate that none of the other tasks allowed or encouraged subjects to use paired-associate strategies.

On the memory span factor UNBM-C, anomalous loadings of .144 and .180, respectively, are for the "control" versions of the free-recall (FR-C) and serial-learning (SL-C) tasks. One may speculate that this is because when these tasks are unencumbered by complications, subjects can use memory span strategies to store sequences of free-recall and serial-learning stimuli.

Anomalous loadings on the factor UNBM-D were plentiful, as follows:

.387	FR-AB	Free-recall, abstract words
.296	FR-II	Free-recall, crossed associates
.270	FR-CA	Free-recall, conceptual associations
.237	SL-M	Serial learning: matching (Positioning)
.211	FR-CO	Free-recall, concrete words
.142	PA-CA	Paired-associates, paired categories (Conceptual interference)

A common element in these variables, shared with those that define the factor, is possibly that good performance can result from alert noting and recall of "events" as such--occurrences of unusual or unexpected associations (in FR-II), occurrences of abstract nouns (in FR-AB), instances of categories (in FR-CA), or positioning of items in a list (in SL-M). Among the defining variables, SF-Z emphasizes being sensitive to the frequency of events, and RR-D calls for noticing (during stimulus presentations) of words that have previously had occurrences in the list (as "events"). Possibly this factor could be referred to as indicating an event-noting ability or strategy.

Anomalous loadings on factor UNBM-E are as follows:

.313	LD	List discrimination
.299	SF-Z	Situational frequency judgment
.270	FR-S	Free-recall, spaced and massed
.261	RR-D	Running recognition

These variables share with the defining variables (scores on verbal discrimination tasks) the fact that good performance could arise from alertness in noting not only the occurrence of events but also the noting of aspects or attributes of those events--the member of a pair tagged as "correct," the list in which an item appears, the fact that an item is repeated (in both SF-Z and FR-S), or the position of an item in a list (in RR-D). This "verbal discrimination" factor may therefore be interpreted tentatively as reflecting a process of "attribute" noting. At least, this is a hypothesis that might be explored in future research.

Information-Processing Factors in a Task Studied by Hussy and Scheller (1976)

Because of the relative unavailability of full information, we can do little more than draw attention to three factors included in a study by Hussy and Scheller (1976) of correlates of variables from a "stochastic-ergodic" information-processing task that involves a subject's ability to infer the partly stochastic rules that determine the sequence with which a series of symbols is presented. Essentially, this is an elaborate probability learning task; it also entails the subject's ability to detect which symbols are used in a particular sequence, and, in a second phase of the task, to detect a change of the rules and conditional probabilities that is introduced into the sequence after a certain criterion performance is achieved in an initial phase. In a third phase, the rules (apparently--the report is not clear) revert to those of the original phase and the subject's ability to infer those rules is again observed, as in the other phases, by the number of trials taken to make a criterial number of correct guesses of sequences. In an elaborate factor analysis done by the Tryon-Bailey method, scores from the three phases of this task were correlated with variables presumably measuring cognitive styles of "cognitive complexity" and "cognitive flexibility." Each of the three variables from the stochastic-ergodic task was associated with a different factor (there were six factors in all). The "information generation" score (derived from Phase I) was associated mainly with measures of cognitive flexibility (Scott, 1962), constituting what we shall call factor HUSC-B. The "information reduction" variable, derived from Phase II, was associated with factor HUSC-C, loaded chiefly with measures of "cognitive complexity" that were also derived from Scott's procedures, which involve an object- or concept-sorting task. A second "information reduction" variable, derived from Phase III, was associated, in factor HUSC-F, with several other measures of cognitive complexity. We can only speculate about how these factors might be related to any that have been discussed above. The task has certain aspects of inductive reasoning such that at least one of these factors might be related to the factor Induction that is identified in the conventional psychometric literature (Ekstrom, French, & Harman, 1979, pp. 19-22). In any case, Hussy and Scheller's information-processing task appears worthy of further study.

Factors Involving General Intelligence, Verbal Ability, and Special Knowledge or Skills

A number of the studies examined here disclosed factors that resemble factors found in the traditional psychometric literature; indeed, this was undoubtedly because many of the studies included conventional psychometric measures in their sets of variables. These factors cannot be readily classified in terms of the paradigms in which their variables would be categorized. The factors are not very clearly identifiable because the studies did not, in general, include a sufficient number of variables to differentiate the factors in the way that factor-analytic design would require. We list and discuss them briefly, preparatory to considering relationships between ECT variables and conventional psychometrically defined abilities.

Factor CORB-A is probably the clearest example of a factor arising from psychometric tests. With high loadings on various operational intelligence and personnel selection tests, it emphasizes reasoning and verbal knowledge abilities; to the extent that the tests may be speeded, it may also reflect some variance in the rate at which subjects perform these tests. The factor showed little or no relationship to any of the measures derived from the investigators' "GRIP" (Graphic Information Processing Tasks) battery.

Similarly, factor HULL-A arises mainly from a series of measures of traditionally defined mental abilities; it has high loadings on scores in Verbal Reasoning, Space Visualization, Numerical Reasoning, Numerical Ability, and Hidden Figures. In the conventional factor-analytic literature, these scores would all fall on different factors, but the factors themselves are typically found to be intercorrelated to a certain extent in such a way as to reflect, in common, the operation of a "general" factor of intelligence and/or speed in performing psychometric tests. Factor HULL-A probably reflects this general factor. The factor also has loadings on several measures derived from a so-called "Sunday + Tuesday" task--an experimental task in which, for example, the subject is asked to convert two days of the week into numerical equivalents, add these equivalents, and then convert the sum back into a day of the week (using, in this case, modulus-7 arithmetic). It is not surprising to find performance in such a task correlated with scores on a Numerical Reasoning test; the task involves fairly complex sequential reasoning operations. The investigators are inclined to call this factor "rapid reasoning" and feel that it reflects ability to make transformations of information in short-term memory (we would classify the task under Paradigm 8). The task resembles certain types of tasks involved in numerical reasoning tests, and it could easily be converted into the form of a paper-and-pencil psychometric test. The factor shows little or no relation to variables derived from ECTs such as Posner-, Sternberg-, or Neisser-type tasks, and thus the factor-analytic results give only weak support to the investigators' claim that "intelligence" of the traditional kind can be measured through ECTs.

There are a number of examples of "intelligence" factors of more limited scope. Factor JAMB-B has its highest loading on a measure of (language) listening comprehension, along with loadings for "effective reading speed" on long and short passages and scores on the SCAT Verbal Aptitude test. It also has a loading of .51 for accuracy on a Posner-type homonym task, suggesting that accuracy in this type of performance is partly a function of the individual's general language knowledge, particularly if the homonyms tend to include relatively rare or unfamiliar words. Factor JAMB-B is most clearly a measure of verbal ability, reading skill, and other abilities that are picked up in the course of an individual's experience and education. At the same time, the factor analysis of a small table of intercorrelations in these investigators' report shows the expected separation between language comprehension (factor JAMA-A, expressed in either listening comprehension or reading comprehension), and reading speed (factor JAMA-B).

Factor JENS-B connects performance on Terman's Concept Mastery test with that on a Digit Span test; the correlation probably arises from the presence of "g" (general intelligence) variance in both of these tests. It also contains an appreciable loading on a score from the Raven Matrix test, probably for the same reason.

Factor CHAT-D arises from the correlation of the Verbal and Mathematical subtests of the SAT; it also has a weak but possibly meaningful loading on the intercept of the Visual Search task. At the same time it is to be noted that the Verbal score, but not the Mathematical score, has loadings on factors CHAT-B (Slope of the visual-memory-search function) and CHAT-C (memory span). Factor SNML-B, using essentially the same data, has a similar interpretation.

Factor ROSE-D connects SAT score with performance on a so-called Grammatical Reasoning (A-B) task in which the subject has to judge the correctness of statements like "A follows B" or "B is not preceded by A" on the basis of a presented pair of letters like AB. This task, scored for number correct within 1 minute, measures both rate and accuracy of language comprehension, as the SAT also (probably) does, so that it is not surprising that the scores should be correlated, but the respective roles of speed and accuracy in both variables remain unclear.

Factor CORB-E reflects a correlation between a "Password" task and a "Twelve Questions" task and is interpreted by the authors as "sequential reasoning." Both tasks are quite complex, but it is at least of interest that these tasks did not appear on the "general intelligence" factor CORB-A. Possibly the common variance of these tasks has to do with associational or ideational fluency--a factor domain that is represented in the traditional factor-analytic literature (Ekstrom, French, & Harman, 1979, pp. 13-18), rather than sequential reasoning.

Factor EGAN-C has its highest loading (.86) on the Guilford-Zimmerman Numerical Operations test, with smaller loadings on the Verbal Comprehension (.41), General Reasoning (.41), and Perceptual Speed (.42) scores of that battery. It probably represents the usual "general intelligence" factor, but it is of interest that this factor is uncorrelated with either EGAN-A (Spatial Accuracy) or EGAN-B (Spatial Speed), at least in the subject sample used by Egan (1978).

Factor ALRK-E is loaded principally with measures from a Mental Addition task that (following Hitch, 1978) was intended to assess the role of short-term memory in arithmetical carry operations. Although the experimental results tended to confirm Hitch's findings, they leave open the question of whether properties of short-term memory account for IDs, or whether differences in numerical facility, as are assessed by tests of what is commonly identified as factor N (Ekstrom, French, & Harman, 1979, pp. 26-27) account for these differences. It is conceivable, however, that tests of factor N reflect individual differences in short-term memory characteristics, although this is unlikely because the best tests of N are those that do not involve carry operations in their arithmetical tasks.

Factor CORB-B is clearly a Technical Knowledge factor (in areas of mechanics, shop, electronics, etc.) and is of no interest in the present context; it exhibited no interesting relationships with experimental tasks in the GRIP battery.

The View from Factor Analysis: Summary and Comment

For convenience, the various factors that have been identified above are listed in Table 3, with a tabulation of the studies in which they appeared, and the designations given them, according to our analyses.

Very probably this table lists more factors (some 25 to 30) than actually exist in the domain of the ECTs covered in the survey. From the available studies, it is impossible to say how distinct these factors are. In fact, a single study that would exhaustively investigate the identification and distinctiveness of these factors would be an enormous and virtually impossible undertaking if it tried to include all the factors in a single battery given to a common population. This is not only on account of the logistic problems in assembling and testing appropriate subject samples, but also on account of the desideratum, expressed by authorities in factor analysis (e.g., Thurstone, 1947), that each factor be represented by at least three relatively "pure" and experimentally independent tests or variables. If there are actually 30 linearly independent factors in the domain of ECTs, it would take a battery of more than 90 tests to establish them. Not only that: To permit clear simple structure of $\underline{n} = 30$ factors to appear, there are reasons for believing that a subject sample of at least $2\underline{n} + 2^{\underline{n}}$ cases would be required, or an $\underline{N}$ of more than a billion! (Think what the requirements would be in establishing the independence of Guilford's [1967] 120 postulated factors.)

TABLE 3

LIST OF FACTORS AND ASSIGNMENTS, BY DATA SET

(See Codes in Table 2)

Tentative Factor Description	ALRK	BRGR	CHAT	CORB	EGAN	FERO	FRDB	HUFL	HULL	HUSC	JAMA	JAMB	JENS	LANA	LANB	LUNA	LUNB	MAUC	ROBA	ROSE	ROFE	SNML	UNDM	WHIA	WHIB
Visual Threshold												D													
Perceptual Closure				G																		E,F?			
Hand Movement Speed													C											B	
Fine Motor Head Control																				B?					
Simple Reaction Time														A		A?			A	C?					
RT to Complex Sequential Events																			B						
Slope of CRT per Bits													A			A?	A?								
Accuracy of Complex Info. Processing																			C						
Accuracy of Semantic Information Proc'g															C										A?
Perceptual Speed	C?			C					B			C?													
Spatial Speed					B																				
Spatial Accuracy					A																				
Speed of Mental Comparison	A?		A						E?			A				A?					A	C			
Slope of Visual & Memory Search	F?		B				A?	C?	C?												C	B?			
Speed of Semantic Processing															A		B?				B			A,C?	
Encoding Multiletter Arrays							B																		
Phonemic Translation							C																		
Depth of Processing Word Recognition							E																		
Control of Articulation							D										C								
Stroop Reading Task																				A					
Memory Span (Registration)	B?	B	C			B?		A?						C?	B	C?						D	C		
Memory Span (Delayed; Interference)		A						D?	D?																
Memory Span (Proactive Inhibition)		C																							
Free Recall (Secondary Memory)	D?			F		A?		B?								B?		A	D				A		
Free Recall (Primary Memory)								E?											E						
Paired Associate Learning				D?										B?				B					B		
Verbal Discrimination Learning																							E		
Memory for Complex Events																	D?						D		
Information Generation; Reduction										B,C,F.															
General Intelligence, Verbal Ability Verbal Ability, etc.			D	A	C				A		A?	B	B	C?						D		B?			
Reading Speed											B														
Reasoning				E																					
Technical Knowledge				B																					
Numerical Ability	E?																								

If factor-analytic methods are to be used to investigate the dimensionality of IDs in ECTs, it will be necessary, therefore, to rely on studies that focus on small sets of variables in the various subdomains, with the hope that eventually the structure of the total domain can be inferred from whatever structures emerge in subdomains and in analyses of samples of variables selected from the subdomains.

On the other hand, since factor analysis is chiefly concerned with common factor variance, i.e. variance that is shared between two or more variables in a correlation matrix, it cannot readily indicate the possible importance of specific variance, i.e. reliable variance present in only one variable in a matrix. That is, it cannot indicate whether this variance might be useful to investigate by trying to identify it as common factor variance in further studies. The survey of factor-analytic results conducted here has not drawn attention to possible instances of important specific variance. For example, inspection of the data in the study by Rose (1974) indicates that there is probably reliable variance derivable from the Shepard-Teghtsoonian running recognition task, but no variable from that task was included in our factor analyses of Rose's data because these variables had few if any substantial correlations with variables that were included in the factor analyses. Questions concerning specific variance are considered in the next chapter, addressed to the examination of the individual task variables.

Although this chapter has been devoted to the factor analysis of variables in ECTs, it may be noted that it is difficult to draw any line between factors identified in ECTs and factors identified in the "traditional" psychometric literature. Factors in the latter domain can frequently be found to have their counterparts in the former domain. The experimental methodology in the former domain does, however, permit greater precision and control of stimuli, conditions of response, and measurement. Egan's (1978) study is an interesting example of one that uses careful experimental methodology to re-examine psychometric variables. The advantages accruing to the experimental study of ECTs are only now beginning to be realized; certainly they have not been fully capitalized on in the studies done to date and reviewed here. Many of the difficulties we have had in interpreting and cross-classifying the factors have stemmed from failure on the part of investigators to take full advantage of available experimental technology. For example, to reiterate a point already mentioned perhaps too many times, there has been a frequent failure to distinguish between decision time and movement time.

For lack of space and time, we have made relatively little attempt to interpret factors in terms of processes. More attention is devoted to this problem in the subsequent chapter. Nevertheless, it is already clear that certain types of processes and tasks are underrepresented in the factor-analytic and correlational studies done to date. One such process is what is commonly called encoding (the process REPFRM described in Chapter 1). Although undoubtedly this process occurs in nearly all the tasks studied, measures of encoding processes distinct from other processes have not been developed or utilized in the factor studies. Similarly, the storage and retrieval processes FOCORP and FICORP have not been measured in ways that might make them identifiable in factor-analytic studies.

It is believed, incidentally, that the present chapter is a methodological achievement in that it demonstrates the utility of graphical, oblique simple-structure factor rotation methods in clarifying the patterns of results. If there had been reliance solely on the results of Varimax analyses of principal component analyses, the results would have been much less clear and the factors would have been more difficult to cross-identify. There were even instances where Varimax results would have been somewhat misleading, e.g., the analyses of the three data sets (Days 1, 2, and 3) from the study by Rose (1974), where the Varimax results tended to overemphasize the dominance of variables from the Stroop task--shown to be actually complex, factorially, by the oblique rotations.

The chapter also appears to be an achievement in the theoretical domain, in that it demonstrates the utility of correlational and factorial methods in summarizing large bodies of evidence in such a way as to give the theoretician a manageable set of findings to interpret, at least on a tentative basis and in the prospect of formulating hypotheses for further investigations.

Chapter 4

INDIVIDUAL DIFFERENCES IN ELEMENTARY COGNITIVE TASKS: THE VIEW FROM TASK ANALYSIS

Introduction

In this chapter, the focus is on the individual elementary cognitive tasks (ECTs) that were investigated in the studies listed in Table 1 (pp. 75-80). We consider a number of matters that pertain to the extent and meaning of individual differences in performance on these tasks: the central tendencies, variances, and distributions of performance measures, their reliability, their correlations with performances on other ECTs and with psychometric measures (including reference to factor-analytic results, where available), the degree to which they can be affected by practice and training, and the conditions under which they can apparently best be measured. Discussion of such matters is what is meant here by "task analysis." (It is recognized that the phrase has other meanings, e.g., see McCormick, 1976.) Partly for convenience and partly because there seems to be some theoretical justification for doing so, the ECTs are discussed according to the paradigms by which they have been tentatively classified. The information given in this chapter is limited largely to what is available from the studies selected for treatment; limitations of time and space preclude reporting a detailed literature search for every ECT considered. If no statement is made about some aspect of a task or its measurement (e.g., reliability, practice effects), the likelihood is that little or no information is available on the matter, at least from the literature surveyed.

ECTs Classified Under Paradigm 1 (Perceptual Apprehension)

Tasks in this classification are of three general types: (1) duration threshold tasks, in which one measures the amount of time required by a subject to apprehend a non-degraded stimulus; (2) perceptual closure tasks, in which the subject's ability to apprehend and interpret a stimulus that is in some way ambiguous or degraded is observed; and (3) tasks in which the subject's ability to apprehend a stimulus despite interference of competing stimuli is the focus of interest. The stimuli may be given in either the visual or the auditory modality, and may be of different types and contents: e.g., pictures of objects and scenes, or printed or spoken symbols (digits, letters, letter strings, words). On the whole, information on IDs in performance of these tasks is sparse.

Visual Duration Threshold for Pictures of Objects

From Wingfield's (1968) report, we can conclude that the visual apprehension threshold for pictures of ordinary objects is about 16 msec when the picture is followed by a blank field, or about 105 msec when the picture is followed by a visual mask. These data are for pictures whose names are of moderate frequency (log p = -5.4, or SFI = 46); name-word frequency is significantly correlated with threshold (-.53 without masking, -.44 with masking), but the effect is overall rather slight. Wingfield gives no information on IDs in visual duration thresholds, but such IDs could conceivably be appreciable and of importance in evaluating cognitive abilities. Measures of VDT for pictured objects should be studied factor-analytically.

Visual Duration Thresholds for Printed Symbols, Letter Strings, and Words

Jackson and McClelland (1979) investigated two tasks of this type: a "single letter" threshold task and a "letter separation" task. In the former, the average threshold for identifying a letter in a "blank" line (without spatially preceding and following X's) was 67.9 msec (S.D. = 4.4 over subjects) for "fast" readers and 66.0 msec (S.D. = 4.1) for "average" readers, there being no significant differences between the two groups of readers (university students). Corresponding means and S.D.s for thresholds when the letter occurred in a "filled line" (preceded and followed by X's) were 83.2 (S.D. = 5.2) and 84.7 (S.D. = 4.1), again with no significant difference between groups. Performance on this task, averaged over blank and filled-line conditions, had a correlation of .37 with performance on the letter-separation task, in which two letters had to be reported from different positions in the visual field, either in a blank or a filled line. The two tasks appeared on what we call a Visual Duration factor in our factor analysis of Jackson and McClelland's data, unrelated to other factors in the analysis except for a factor correlation of .34 with a language knowledge factor. This correlation may reflect experience in reading. Jackson and McClelland present no data on central tendencies and variances of performance on the letter-separation task.

Frederiksen (1978) studied a "bigram identification" task in which subjects had to report pairs of letters (bigrams) seen in a display that was temporally preceded and followed by a visual mask and that lasted from 90 to 100 msec (reported to be the shortest duration time that would allow 95% of the stimulus letters to be correctly reported). This task was the basis of two derived measures, Scanning Speed (rate of scanning estimated from RTs for bigrams in positions 3 and 4 vs. those in positions 1 and 2 of a four-position display), and Bigram Probability Contrast (a measure of the "penalty in processing time" brought about by reduced bigram probability in English orthography). There were apparently reliable differences in scanning speed, interpreted on the basis of a factor analysis as reflecting speed of grapheme encoding. IDs in the bigram probability contrast measure were interpreted as reflecting possession of, or access to, knowledge about grapheme-phoneme relationships in decoding letter strings in English.

Despite considerable investigation of factors that influence word-recognition thresholds, information on the role of IDs is scanty. For a list of seven words that the report (Rose, 1974) does not specify or characterize (e.g., in terms of frequency in the English language), average visual duration thresholds were in the neighborhood of 50 msec, with a wide range and moderate test-retest reliabilities (Day 1 vs. Day 2, $\underline{r}$ = .58; Day 2 vs. Day 3, $\underline{r}$ = .76). This measure had few if any significant correlations with other tasks in Rose's investigation; communalities were low in our factor analyses of Day 1, Day 2, and Day 3 data. Correlations with SAT-V scores were non-significant, and there was no average improvement in performance over the three days. These results are generally in line with those from studies by Richards and

Platnick (1974) and Platnick and Richards (1977). In the first of these studies, thresholds were related to SAT only for low-frequency words (1 to 10 per million); in the second study, thresholds appeared to be significantly related to measures of speed of closure, memory span, and perceptual speed, but then only weakly. A possible complicating factor is the subject's visual acuity; Platnick and Richards cite Spielberger and Denny's (1963) estimate that the correlation of visual acuity and threshold for high-frequency English words is -.50. Other complicating factors are word length (Richards & Heller, 1976) and word attributes such as concreteness vs. abstractness (Richards, 1976; Cohen, 1976). Cohen found no correlation of word-recognition thresholds with Otis IQ (though in a somewhat restricted sample), and no interaction of IQ with word frequency.

Visual Closure Tasks

Included in Cory, Rimland, and Bryson's (1977) "GRIP" (Graphic Information Processing) battery was a test of Recognizing Objects in which "partially blotted-out" pictures of objects were presented with successive additions, over trials (frames), of the amount of visual information presented. The score was the number of frames shown before the objects were identified. (Latencies of response were also taken, but the report gives no information on these.) The mean score was given as 15.95 (S.D. = 4.13) but since the report does not mention the number of items one cannot say what amount of information was necessary before recognition was attained by the average subject. In a principal factor reanalysis of these authors' correlation matrix, the test had a communality of .34 and a loading of .37 (after sign-reflection for reversed scoring) on factor CORB-H, which we identify as a Pattern Perception factor. It is difficult to interpret this result. One would have expected this test to load on a Perceptual Closure factor such as CORB-G but the loading on that factor was only .24.

A somewhat similar task was studied by Frederiksen (1967), who presented color slides for object recognition in a sequence of 15 stages of decreasing ambiguity. Ambiguity was manipulated by gradually reducing the optical blurring of the slides.

Frederiksen found that the point at which the picture was first recognized depended critically on whether a "wide" or a "narrow" range of ambiguity was used. Subjects could recognize a picture with a given degree of blurring better if they had not previously seen the picture in several stages of greater blurring. Failure to recognize a picture was interpreted as occurring because a subject who had seen a series of highly blurred presentations was likely to entertain, and persist in entertaining, wrong hypotheses about the identification of the object picture. Possibly the anomalous result for Cory et al.'s (1977) Recognizing Objects task came about because they used what Frederiksen would call a "wide" range of ambiguity. One may suggest that in the construction of visual closure tasks for measuring the Perceptual Closure factor, the item difficulty (in terms of amount of information) must be set at an appropriate level. In Frederiksen's data, subjects in the "narrow range" condition had scores (reflecting points on the ambiguity scale at which recognition was attained) that were highly predictable (multiple R = .77), chiefly from tests of Speed of Closure and Visualization ability. For the "wide range" subjects, scores were less predictable (multiple R = .51), and the chief predictor was a test of Spatial Scanning ability.

Auditory Closure Tasks

Frederiksen (1967) developed an auditory analog of the Visual Recognition test; spoken words were repeatedly presented, but with decreasing amounts of masking sound, until the word was recognized. As in the visual task, subjects were more successful on a given item under the "narrow range of ambiguity" condition, i.e., when the item had been preceded by fewer (if any) previous presentations with greater amounts of masking. Under the narrow range condition, scores were highly predictable (multiple R = .76) from measures of Flexibility of Closure and Verbal ability, but the prediction was not significant (multiple R = .36) under the wide range condition.

Correlations (corrected for attenuation!) between Auditory Recognition and Visual Recognition test scores were .18 for the wide range condition and -.03 for the narrow range condition. Thus, visual and auditory closure abilities are apparently uncorrelated.

Tasks Measuring Auditory Apprehension of Competing Stimuli

The single task identified in this category was the Dichotic Digit Pairs test studied by Robertson-Tchabo and Arenberg (1976). "An item consisted of two different digits presented simultaneously, one to each ear. . . . The task was to identify both digits" (p. 78). In our factor analysis, this test had a communality of only .25 and a very weak and probably insignificant loading of .26 on factor ROBA-E (interpreted as "Primary Memory"). If this test is at all reliable (no information is given on this matter), its variance is thus largely specific; possibly it deserves further investigation.

ECTs Classified Under Paradigm 2 (Reaction Time and Movement Time)

IDs in reaction time (RT) have been studied for at least a century and a half (see, for example, Woodworth, 1938, Chapter XIV). It has often been thought that such IDs are relatively specific and of little general interest. In recent years, from the perspective of information-processing psychology, renewed efforts have been made to find relations between certain RT tasks and performances considered to be of more general significance.

RT tasks can be classified according to the criteria established by Donders (1868), with a few additional categories: (1) "simple" RT tasks (Donders' *a-reaction*) in which there is a uniform stimulus and a uniform response; (2) RT when the subject is asked to respond to only one out of *n* alternative or possible stimuli (Donders' *c-reaction*); (3) "choice" RT in which the subject is required to make a different response to each of *n* possible stimuli (Donders' *b-reaction*); (4) RT experiments intended to investigate IDs in attention, flexibility, and time-sharing ability; (5) tasks for measuring IDs in speeds of certain voluntary physical movements.

Simple RT Tasks

In a sample of 64 high school students, Lunneborg (1977, Study 1) measured Motor Reaction Time as the median time for the subject to respond by a key press to the onset of a "+" centered on a computer-terminal screen. No data are given on central tendencies or variances, but this measure correlated significantly with a number of other laboratory task variables (choice reaction time, [Sternberg] search slope and intercept, dichotic category, dichotic difference, clustering base, and clustering difference) and also with all but one (Clerical number) of a series of psychometric tests. In further studies, however, the Motor Reaction Time variable was not used, but other reaction time measures that showed significant correlations in this high school sample exhibited mostly non-significant correlations in the subsequent studies--even a high school sample that was generally comparable to that tested in the first study. Lunneborg's report is chiefly concerned with attempting, without complete success, to explain the discrepancies among the studies. One possibility that Lunneborg apparently did not consider is that the substantial correlations in the first study may have arisen from the presence of a few "outlying" cases that boosted the correlations above the chance level. Also, it would appear that Lunneborg made no transformations of the reaction time measures, distribution of which is generally found to be substantially skewed in a positive direction. Use of untransformed measures would be particularly likely to give an advantage to "outlying" cases in boosting correlations above the chance level. Our recommendation would be to use a reciprocal transformation in correlating reaction time measures with other variables.

In her study involving the use of a simple RT task as a "secondary" task in conjunction with other tasks, Lansman (1978) collected data under a control condition in which simple RT was measured in relative isolation from any secondary task. In her sample of university students, mean RT was 288, with a S.D. of 36, range 230 to 395, and reliability of .76. The measures in the control condition correlated .52 with RT as probed in an "easy recall" condition during a Continuous Paired Associate task, and .36 as probed in a "hard recall" condition. Mean RT was considerably greater when measured as a "probed" secondary task: 480 (S.D. = 117, range 288-828) under the "easy recall" condition, and 513 (S.D. = 133, range 270-920) under the "hard recall" condition. These measures had reliabilities of .91 and .93 respectively, and probably reflect variation in attentional processes, i.e. ability to switch attention from the learning task. Simple RT came out with a moderate loading of .50 on factor LANA-A that we interpret as a Simple Reaction Time factor, but this factor may be more concerned with the attentional processes measured under the secondary task condition. None of the RT measures was correlated significantly with the WPC Verbal composite.

Keating and Bobbitt (1978) also collected measurements of simple RT to a red light, on groups of different ages. Mean RTs in msec (with S.D.s) for groups of high vs. average ability as indicated by age-appropriate intelligence measures were as follows:

	Average Age		
	9	13	17
High ability	285 (43)	242 (30)	235 (33)
Average ability	311 (38)	260 (42)	233 (33)

The apparent interaction between ability and age, whereby ability is better correlated with simple RT at the younger ages, was not directly tested by the authors, whose ANOVA was concerned also with a CRT (choice reaction time) measure. It is reported that there was no main effect for sex. The data are generally consistent with previous studies of age in relation to simple RT (Miles, 1942; Goodenough, 1935; Bellis, 1932-33) except that some studies do show faster RTs for boys.

The reaction time measurements taken by Robertson-Tchabo and Arenberg (1976) were taken in the context of a "vigilance task." The simple reaction time task was to respond to the onset of a zero presented visually. No data on central tendencies, variances, or reliability are given. In our factor analysis of their data, the simple RT measure, taken as the median response latency over 15 trials, loaded most highly on factor ROBA-A, interpreted as Reaction Time to Simple Events.

Jensen's (1979) report of data from a Reaction Time and Movement Time apparatus includes data that can be regarded as indicating simple reaction time, excluding movement time. At the 0-bit condition, the median RT appears to be about 280 msec, from Jensen's figures, for a group of 50 university undergraduates. The intercept values are slightly higher, up to about 330, for several other normal groups of different ages. They are strikingly higher, however, for two retarded groups: about 485 for mildly retarded and borderline young adults, and about 630 for severely retarded young adults. In our factor analysis of Jensen's data, the intercept value was most highly related ($\underline{r}$ = .44) with mean SD of movement time, and loaded highly on what we interpret as a Speed of Movement factor. Jensen reports high reliabilities (≥ .90) for his RT measures.

From the above studies, it appears that there are highly reliable IDs in simple RT that tend to correlate with other reaction time measurements--choice RT, for example, at least to the extent that they provide an indication of the intercept or average values of such measures. To the extent that they are correlated with mental age in younger children and in retarded individuals, they provide some indication of mental or organismic maturity, but for the normal adult population they show no reliable correlation with intellectual abilities.

"Simple" Choice-Reaction Tasks (Donders' c-reaction)

Donders' c-reaction task may be called a "simple" choice-reaction task because it requires that the subject be alert to respond to only one out of $\underline{n}$ possible stimulus types or situations. Such tasks were used in two of the studies surveyed here. In Whitely's (1977) study, a task called Choice Reaction was used "to represent a baseline response decision task which involves little cognitive mediation." Subjects viewed a series of slides with either O's or +'s and were instructed to press a response button on seeing a slide with a "+." Mean reaction time was 720 msec, S.D. = 360; the distribution was probably skewed, and the mean is probably greater than the median (not reported). Nevertheless, the much greater magnitude of this "simple" choice-reaction time as compared with simple RT is striking. In fact, it is greater than the average "complex" choice RTs reported below. Whitely used no other pure reaction time measures, although latencies were taken on a variety of cognitive tasks involving analogical reasoning, and the choice-reaction time measure had no significant correlations with these latencies--which were much longer, on the average--in the range of 2 to 8 seconds.

Robertson-Tchabo and Arenberg's (1976) choice RT measures were taken in the context of a "vigilance" task in which a succession of digits was presented, visually, at the rate of one per second. The choice reaction measurements can be classed as c-reactions because the subject had to be alert to respond only under certain conditions. In the task labeled C.R.T. 1, the subject was to respond to a particular digit; although the report is not clear on this point, we assume that there was only one digit (either 1, 2, 3, 4, 6, 8, or 9) that the subject was to respond to during presentation of a particular sequence of digits. In C.R.T. 2, the task was to respond to any even digit (or any odd digit). In C.R.T. 3, the subject was to respond to an even-odd sequence of digits (or an odd-even sequence), and in C.R.T. 4, to "any two contiguous even digits as well as any two contiguous odd digits." Obviously, the task condition increased in difficulty. For each task, the dependent variable was the median response latency of correct responses. The number of correct responses was also recorded for the tasks C.R.T. 3 and C.R.T. 4. The investigators do not report central tendencies, variances, or reliabilities. The communalities (ranging from .75 to .81) in our factor analysis of their data may be taken as lower bound estimates of reliabilities. The latencies on the tasks C.R.T. 3 and C.R.T. 4 defined a factor ROBA-B that we interpret as "Vigilance RT to Complex Sequential Events"; the accuracy measures on these tasks defined a further factor ROBA-C that we interpret as "Accuracy of Complex Sequential Processing in a Vigilance Task." The leadings on ROBA-B were higher as the complexity of the task increased; the easier tasks shared some variance with factor ROBA-A, interpreted as RT to simple events. The three factors had low positive intercorrelations: AB, r = .23; AC, r = .29; BC, r = .15. Because the study contained only a limited variety of reaction time tasks, we cannot easily relate these factors to ones found in other studies, but the evidence for these three factors, at least, is fairly strong on account of the sample size (N = 96 "healthy educated men," age range 20 to 80). (The authors state that their factor structure for the total group was also found when the sample was analyzed separately by four age groups; we cannot confirm that for our own re-analyzed factor structure because the authors do not report the separate correlation matrices.)

"Complex" Choice-Reaction (b-reaction) Tasks

The "complexity" in these tasks arises because the subject is required to make a different overt response to each of n alternative, easily differentiable stimuli. Generally, choice-reaction times are on the average longer than either simple reaction times or "simple" choice-reaction times. Egan (1978) obtained means (and S.D.s) of 350 (70) and 340 (50), respectively, on two successive days, in a "Yes-No Decision Task" in which subjects pressed a button corresponding to whether the word "YES" or "NO" appeared on a slide. (These measures include both decision time and any movement time involved.) Average percentages correct (and S.D.s) were 87.2 (2.4) and 87.9 (2.2) on the two days. Measures on this task were not included in Egan's factor analysis of his data; the latencies, however, tended to correlate, though non-significantly, with latency measurements on computerized versions of visualization and block rotation tests. In Egan's words, ". . . as expected, response latency to Yes/No items tended to correlate more strongly with intercepts[,] which include decision and output latency[,] than with slopes[,] which measure spatial transformation latency" (p. 28).

Data on age and ability differences in choice reaction time from Keating and Bobbitt's (1978) study are of interest. Here we give the average latencies (and S.D.s), as well as an estimate of the slope (the difference between 2-choice RT and simple reaction time), derived from their Table 1:

		Age 9	Age 13	Age 17
High ability:	Mean (S.D.)	689 (110)	468 (27)	430 (30)
	Slope	403	226	195
Average ability:	Mean (S.D.)	729 (88)	520 (52)	467 (24)
	Slope	418	260	234

Keating and Bobbitt's RT tasks included the complication that the subject had to translate the color of the stimulus light (green or red) into a position code (left or right) and thus their latency measurements may be on the average longer than those that might be obtained in a task that did not include the translation component; also, their latencies included movement times. Keating and Bobbitt analyzed their data in terms of an ANOVA design using simple and choice RT conditions as two experimental levels; there were significant main effects for age, ability, and level, and a single significant interaction between age and level. The ability × level interaction was only marginally significant, but such an interaction seems more apparent when the slope values (given above) are examined: The slope values for high vs. average ability children differ increasingly with age.

Yet, Keating and Bobbitt's results seem rather inconsistent with those obtained by Jensen (1979), who used an experimental procedure whereby slope values could be obtained over 0, 1, 2, and 3 bits of information (i.e., 1, 2, 4, and 8 choices), and whereby decision times were distinguished from movement times. For 50 university students, one can estimate the slope (increment of RT per bit) at about 23 msec, a value much smaller than anything in Keating and Bobbitt's results, even at age 17. Perhaps the data from Keating and Bobbitt's experiment are inflated because of the code translation component in the 2-choice task, as suggested above. Further, the slopes from Jensen's data do not seem to vary much over a number of groups of "normal" individuals ranging from the 6th grade to the university level (see Jensen's Figure 6); the slopes are deviant only for mildly and severely retarded groups. (It is striking that the slope is virtually zero over 1 to 3 bits for a severely retarded group, with a very high intercept.) In fact, although Jensen claims that slope correlates with Raven intelligence test scores, the intercepts, not the slopes, are what chiefly differentiate RT/bit functions for low, middle, and high ability groups at the 9th grade level (see Jensen's Figure 4). If intercepts are related to Raven intelligence test scores, this would mean that the factor Simple Reaction Time or Speed of Movement is more related to Raven intelligence scores than the factor we have called (p. 91) Slope of Choice Reaction Time. As already suggested, the correlation of slope with Raven matrix scores found by Jensen (actually only .41 in absolute magnitude, for N = 50 university students) may reflect some involvement of speed in Raven scores, even though Jensen insists (p. 27) that he does not give his tests under speeded conditions. Our reanalysis of Jensen's data (Appendix A) shows that the slope function is not related to scores on Digit Span or the Terman Concept Mastery Test, and the intercorrelations are essentially zero.

Keating and Bobbitt present (1978, Table 2) correlations between CRT and certain "processing parameters" from other cognitive tasks. For all subjects, for example, CRT correlates .78 with (Posner) physical-condition sorting time and .81 with the intercept of the (Sternberg) memory search function. Keating and Bobbitt regard these variables as measures of "similar [processing] steps" and contrast these high correlations with the generally much lower correlations found for pairs of "dissimilar steps." It must be pointed out, however, that all these correlations are for subjects pooled over age groups; they are inevitably confounded with age effects. Within-age-group correlations for these variables would have been much more informative; presumably they would be much lower than those cited for the pooled groups.

Choice RT measures were used in two other studies included in our survey, but shed little light on questions implicit in the above discussion. Lunneborg (1977) found highly inconsistent results for his choice RT measures over three samples; while the choice RT measures were substantially correlated with variables from other laboratory tasks and with a series of psychometric tests in one high-school sample, they exhibited very low or insignificant relations in other samples. Problems with the Lunneborg results include the following (some of which have already been mentioned): The variable in his Study 1, at least, was a difference score (difference between a 2-choice RT and a 1-choice RT, an estimate of a slope/bit function); this variable, and the variables used in Studies 2 and 3, extended only to one bit of information (i.e., 2 choices, as opposed to the 4 and 8 alternatives in Jensen's experiment); and there is no evidence that transformations of variables were considered in the light of possible distributional skewness and presence of outliers.

Rose (1974) used a 4-choice RT task that involved speed-accuracy tradeoff, along with a "control" RT task that omitted the "deadline" instructions. RTs from the control task (averaging in the neighborhood of 500 msec) improved significantly over three days, but had reliabilities of only .56 (Days 1-2) and .72 (Days 2-3). A "slope" variable that reflected the effect of increasing time pressure to meet a "deadline" had even lower reliabilities: .22, Days 1-2, and .61, Days 2-3. Since the test battery included no simple RT task, it yielded no information on the slope function re bits of information (number of choices) nor its possible relations with other variables--laboratory or otherwise. The "control" RT had weak loadings on the factor ROSE-C that we have interpreted as a Simple RT factor.

In short, evidence available at this time is far from clear as to the nature and parameters of individual differences in RT (either simple or choice, although these are generally correlated to a substantial degree) or their relations with other laboratory tasks and with traditional psychometric measures of intellectual abilities. Further investigations responsive to suggestions made here could be expected to shed much light on these matters.

Tasks Used in Investigating Further Aspects of RT Abilities

Keele, Neill, and de Lemos (1978) have obtained promising results in using certain RT tasks to measure flexibility of attention. Several of these tasks have high reliabilities and show interesting intercorrelations. A "benefit" measure from a Priming Task, reflecting how much a subject is advantaged by being informed in advance as to which of several alternatives in a choice reaction task is most likely to be presented, was found to have a reliability of .89 and significant correlations with certain measures from a Rare Event task and an Alternation task which also had high reliabilities. Both of these latter tasks seem to yield measures of how much a subject is benefitted by cues or disturbed by unexpected (low probability) stimuli in a choice-reaction context. These tasks should be further investigated along with the simpler tasks discussed above, including the "probed" RT investigated by Lansman (1978), which resembles Keele et al.'s tasks to a certain degree.

Similarly, promising results on individual differences in a "time-sharing" RT task are reported by Hawkins, Church, and de Lemos (1978). This task, employing the double-stimulation or psychological refractory period (PRP) paradigm, apparently can measure the degree to which a subject's response to a stimulus is affected by the prior or simultaneous presentation of another stimulus requiring a different response. What will have to be clarified further is whether time-sharing is a unitary ability (which it is not, the authors tentatively conclude) and whether it is related to the attentional abilities represented in the tasks studied by Keele, Neill, and de Lemos (1978).

RT Tasks and Measures Emphasizing Movement Time

In his earlier study, Rose (1974) investigated a "Critical" Tracking task inspired by feedback control theory; the task has apparently not been further investigated from an individual differences standpoint although one of its parameters ($1/\lambda$, or the reciprocal of the "effective delay") had the highest reliability of any of the measures in that study. The task resembles those observed in computer games in which the subject has to manipulate a "joy stick" or other device to control the movement of an increasingly unstable stimulus across a computer-terminal screen; it probably involves not only some element of reaction time speed but also ability to perceive changes and rates of movement. A possible drawback in the task as a measure of cognitive abilities is that males are consistently better than females, on the average. Also, there was significant improvement with practice, and thus it may be more a measure of skill than of ability. In our factor analysis of Rose's correlations, the Critical Tracking measure loaded on a reaction time factor along with the "control" choice RT and mean score on a paper-and-pencil version of a Rotated Letters task. From the limited data available, the nature of IDs on this task is as yet very unclear, but because of the importance of tracking behavior in certain jobs and occupations, it would seem profitable to investigate it further.

Jensen's (1979) Reaction Time and Movement Apparatus yields experimentally or logically independent measures of decision time and movement time in a choice-reaction-time task. At zero bits of information (i.e., in a simple RT task), movement time averaged about 210 msec when the subject left a home button and had to press a 1/2" button 6" away, but there were IDs in this that Jensen reported as correlating about -.40 with measures of intelligence such as Raven Progressive Matrices scores. In our factor analysis of Jensen's data for 50 university students, however, Median Movement Time appeared on a Speed of Movement factor JENS-C on which Raven Matrices loaded insignificantly (.14). Fast movement time was associated with high mean SD of movement time and with fast decision time at zero bits (the intercept of the CRT slope function). Further investigation of movement time is recommended not only because of the status of this variable in relation to other cognitive abilities (if this variable can indeed be called "cognitive") but also because, as we have pointed out repeatedly, movement time is frequently involved in a wide variety of RT measurements--many to be discussed below under Paradigms 3 and 4.

Finally, Rose's (1974) work on a version of Fitts' Tapping task is possibly relevant to the study of performance on a wide variety of cognitive tasks, especially those involving rapid and accurate marking on paper-and-pencil answer sheets. The original Fitts' task (Fitts, 1954) involved moving a hand-held stylus from a "home plate" to a target plate either at the right or the left, depending upon a cue from signal lights. The distance and width of the target plates were varied and the speed and accuracy of target hitting were highly predictable from a mathematical equation derived from information theory. In Rose's paper-and-pencil version, the subject had to rapidly make pencil marks in circles of decreasing diameter and increasing distance arrayed to the left and right on a response sheet; slopes and intercepts of the movement time function were estimated by least squares regression. There was also a "control" task in which time to "tap" back and forth across a vertical line was measured. Control times, intercepts, and slopes all had quite high reliabilities (ranging from .62 to .83). Although control times and intercepts showed practice effects over three days, slopes did not. In our factor analysis of Rose's correlations, the slope (but not the control time) loaded on factor ROSE-B which we interpret as a Movement Control factor, along with mean time in a Letter Search task which could have involved speed and accuracy of performing directed movements to make pencil marks. There were no sex differences.

ECTs Classified Under Paradigm 3 (Evaluation/Decision)

Several ECTs occurring in the studies surveyed here classified under Paradigm 3, perhaps for want of a better place to classify them; we are in fact somewhat dubious about some of the classifications. In all the cases, however, it can be argued that the subjects were required to make some judgment or decision about a stimulus presentation. Either the speed or the accuracy of these judgments, or both, could be observed, and the judgments were not comparisons such that the ECT would be classified under Paradigm 4.

A Dichotic Order Judgment Task

In Hunt, Lunneborg, and Lewis's study (1975, Expt. 4, pp. 206-209), data are reported on a task deriving from the work of Day, Cutting, and Copeland (1971) in which subjects were required to report which of two sounds, presented dichotically and with a minimum lead time (50 msec) between the two sounds, was heard first. Day et al. had reported that right-handed subjects are biased toward perception of stimuli in the right ear as being the lead stimuli, when the stimuli are speech sounds. This accords with the assumption that speech stimuli are processed by right-handed people in the left brain, and that any auditory stimulus is received in the contralateral hemisphere before it is received or processed in the ipsilateral hemisphere. In contrast, a left-ear advantage had been found (again for right-handers, presumably) for the perception of dichotically presented non-speech stimuli such as pure tones of varying pitches. Day had further reported "striking" IDs in the extent of this bias. Hunt et al. speculated that the IDs might be associated with verbal ability. If "high" verbals transmitted information faster, they might have less right-ear advantage. The actual data reported by Hunt et al. were collected by Poltrock for three groups of 16 subjects each, "high," "middle," and "low" in verbal ability as measured by a scholastic aptitude test in use at the University of Washington. No handedness data are reported for these subjects, but one may presume that most were right-handers.

Two stimulus tapes were used, both provided by Ruth Day; the "speech" tape contained 48 pairs of stimuli consisting of all possible pairs of the sounds /ba/, /da/, and /ga/, each possible pair being presented twice in both possible orders, at each of two lead times (50 and 100 msec), with the leading sound being presented at each of the two ears (i.e., 3 × 2 × 2 × 2 × 2 = 48 pairs). The "non-speech" tape was constructed similarly, the three non-speech sounds being a buzz, a hiss, and a tone. Results were reported only for the pairs with the 50-msec lead time, the 100-msec lead time being "easy" and included in the task "mainly as a motivator." Maximum possible correct would therefore be 12 for each ear or a total of 24 for each tape. Reading from Hunt et al.'s Figures 3 and 4 as accurately as we can and doing some arithmetic, we may present the approximate mean scores and percentages for the three groups, as follows:

Lead stimulus:	Left	Right	Total	"Left Ear Advantage"
Maximum possible:	12	12	24	(Left minus Right)
Verbal ability:				
		Speech Sounds		
High	6.05 (50.4%)	5.65 (47.1%)	11.70 (48.7%)	0.4
Middle	4.15 (34.6%)	6.45 (52.7%)	10.60 (44.2%)	-2.3
Low	3.10 (25.8%)	6.10 (50.8%)	9.20 (38.3%)	-3.0
		Non-Speech Sounds		
High	7.15 (59.6%)	7.05 (58.7%)	14.20 (59.2%)	0.1
Middle	8.10 (67.5%)	6.30 (52.5%)	14.40 (60.0%)	1.8
Low	8.10 (67.5%)	7.20 (60.0%)	15.30 (63.7%)	0.9

From these data, Hunt et al. report that high verbals were more accurate in the perception of speech sound order, but that no difference was found in accuracy of perception of non-speech sounds. They also report that the interaction between stimulus type and verbal ability was significant at the .01 level. They graph the "left ear advantage" scores and point out that "both the low and middle verbals show the sort of advantage that would be expected given the type of stimulus," while "the high verbals show no advantage." The interaction between ear of first stimulus and level of verbal ability is reported to be significant at the .025 level. The finding is claimed to confirm the hypothesis that "high verbal subjects are unusually sensitive to the order in which speech information enters STM" (p. 209).

On examination, these interpretations seem strange in the light of the results previously reported by Day et al. For one thing, one would have expected a striking right ear advantage for the group of subjects as a whole, for speech stimuli. The right ear advantage (the inverse of the left ear advantage, of course) was modest, and was maximal in the low verbal group. The left ear advantage for the non-speech sounds was also modest, if it was significant at all, and showed no consistent trend as a function of verbal ability (perhaps it would not be expected to show any such trend in the light of theory). The relatively low success rates for all stimuli and ability groups are also striking. For speech sounds that led in the right ear, success was only around 50%. Success rates were markedly lower than this only in low and middle ability groups when the leading stimuli were in the left ear. In the light of the theory, the results suggest that as ability decreases, there is increasing difficulty in processing stimuli in the right brain. In view of the fact that high ability subjects were successful only at about the level of 47% with right-ear-leading speech stimuli, it seems difficult to conclude that high verbal subjects are "unusually" sensitive to the order in which speech information enters STM. The results are also difficult to interpret because we have no information to judge the level of chance success, which would be somewhere between one-third and one-half, depending on whether subjects always reported at least one of the sounds actually presented or might frequently report neither of the sounds actually presented.

Because of the probable unreliability of data from this ECT, it is unlikely that any score derived from this task would be of use in measuring any important cognitive ability. We have no direct information about the reliability of scores, and no information about possible practice or training effects. No measure from this task was included in Hunt et al.'s factor analysis. The task was, however, studied by Lunneborg (1978) and some information on correlations of its variables, generally low, with psychometric measures is available from that study. Lunneborg also used an analogous Visual Temporal Order Judgment task; a Left Visual score, but not the Right Visual score, had moderate significant correlations with Vocabulary (.25) and Performance IQ (.37).

Lexical Decision Tasks

The lexical decision task is classified under Paradigm 3 because the subject's task is to judge whether a string of phonemes or graphemes (almost always the latter) is a word in the subject's native language. Both speed and accuracy can be observed. The task was introduced by Rubenstein (Rubenstein, Garfield, & Millikan, 1970) to study properties of subjects' modes of access to the "internal lexicon" in long-term memory; the task has also figured in studies of reading behavior. Individual differences in lexical decision performances have received relatively little attention. The most obvious individual difference variable to consider in this connection is vocabulary knowledge (as would be measured by tests of the well-known V-factor). Butler and Hains (1979), looking at RTs in a lexical decision task, find that vocabulary knowledge interacts with word length, word frequency, and age-of-acquisition, in the case of words, and with status of the stimulus as a word or non-word. In the case of words, high-vocabulary subjects take slightly longer for short words, but less time for long words, than low-vocabulary subjects. In the case of non-words, which have uniformly longer RTs than words, high-vocabulary subjects take uniformly longer than low-vocabulary subjects. Thus, for relatively long and rare words, high-vocabulary subjects are quite fast at recognizing letter strings as true words, but they linger longer over non-words, as if engaged in a more exhaustive search of the lexicon. Nevertheless, these authors point out that a considerable portion (roughly 37%, they say) of the variance in their results is due to individual differences that cannot be accounted for by differences on their vocabulary test. This leaves open the possibility that the individual differences could be associated with any of the several sources of IDs in cognitive performances that we are examining here. Investigations of this matter would, however, have to control for word length, frequency, and age-of-acquisition along lines suggested by the Butler and Hains results. Also, correlations with reading speed should be investigated.

Some of the variables observed in the "Meyer" (Meyer, Schvaneveldt, & Ruddy, 1974) task used by Rose and Fernandes (1977) constitute lexical decision RTs. Apparently (the report is not completely explicit on this point) the variables "Word" and "Non-Word" appearing in their correlation matrix, and used in our factor analysis, are RTs to the first string presented in the successive presentation of two words. (Perhaps unwisely, in our factor analysis we did not use a further variable, Encoding Facilitation, derived from the "Meyer" task because its correlations with other variables seemed relatively small. We will not describe or discuss the results coming from the second members of the pairs because they seem irrelevant to the present discussion.) The "word" and "nonword" RTs correlated .64 on Day 1, and .73 on Day 2; nevertheless, these variables did not define a specific or "doublet" factor in the analysis, but appeared with fairly substantial loadings on factor ROFE-B, which we have interpreted as a factor of Speed of Semantic Decisions, along with variables from several other semantic decision tasks to be discussed subsequently. Since the Rose and Fernandes study did not have measures of vocabulary knowledge, reading speed, or other more traditional intellectual variables, it is impossible to say whether this factor ROFE-B is essentially the same as the familiar V-factor, or represents variance over and above V-factor variance. Considering the fact that the "Meyer" task used by Rose and Fernandes used only fairly short and (apparently) relatively common words, there is a strong suggestion that something over and above vocabulary knowledge is implicated in the "Word" and "Non-Word" RTs. Certain results concerning the "Word" and "Non-Word" variables are of interest (from Table 10, Rose & Fernandes, 1977, p. 57):

	"Word" RT		"Non-Word" RT	
	Day 1	Day 2	Day 1	Day 2
Mean	736	647	916	756
Median	715	634	843	737
Standard deviation	112	74	252	113
Reliability (Day 1-Day 2)	.66		.53	

Apparently, the reduction in means, medians, and standard deviations from Day 1 to Day 2 is associated with use of precisely the same series of stimuli on the two days, resulting in what appears to be a practice effect. The low reliabilities may be associated with the relatively small number of items (20); reliability could undoubtedly be increased by lengthening the test. One problem with this test, like others considered here, is that it is undoubtedly partly a measure of reading or word recognition time.

Other Semantic Decision Tasks

Two other tasks studied by Rose and Fernandes (1977) may be considered here. The "Collins and Quillian" task (Collins & Quillian, 1969; Landauer & Freedman, 1968) was originally introduced to test certain theories about "semantic memory"; it is based on the idea that lexical retrieval time will be a function of the distance between two concepts (e.g., between cod and fish, or between salmon and animal) in terms of set-superset and associated property relations. While there have been difficulties in confirming any such hypothesis (Smith, 1978), the task remains of interest as a way of measuring speeds of cognitive processes from an individual differences standpoint. The Collins and Quillian task includes both "instance-category" judgments and judgments of "property relations" (e.g., Shark-Dangerous, for an immediate relation, vs. Barracuda-Breathes, for a more distant relation). It could possibly be better classified under Paradigm 4 because it may demand an implicit comparison process, but we have classified it here because stimuli are presented as single entities for evaluation, in the form of sentences like "A shark is dangerous" or "A barracuda breathes." Sentences requiring positive and negative responses are included with equal probabilities.

Undoubtedly, RTs include reading times and there is a good possibility that this task is simply another measure that is strongly influenced by reading speed. Rose and Fernandes made no attempt to control for subjects' reading speeds, and the variables derived from this task tended to correlate with variables, from other tasks, that may have reflected reading speeds. Rose and Fernandes derived two types of variables from the task: the intercepts and the "slopes" of functions relating RTs to the presumed semantic set-superset or property distance between concepts. Inspection of their correlation matrices for Day 1 and Day 2 data show that the slopes had little correlation with each other, with the intercepts, or with any other variables. Indeed, the slopes had Day 1-Day 2 reliability coefficients of only .21 (Superset items) and .16 (Property relation items). The slope variables are therefore probably not of interest from an individual differences standpoint, and the results tend to deny the theoretical validity of the slope concept in the case of this task. The intercepts, therefore, probably reflect the overall speed with which the task is performed. These intercept variables have reliabilities of .69 (for the superset variable) and .73 (for the "property" variable) and appear fairly strongly on factor ROFE-B which we have interpreted as speed of semantic decisions. Some distributional statistics are as follows:

	Superset		Property	
	Day 1	Day 2	Day 1	Day 2
Mean (msec)	1035	1017	1118	1121
Median	1005	1004	1081	1115
Standard deviation	205	220	257	248

Practice effects were not significant, according to Rose and Fernandes (1977, Table 9, p. 53), as is obvious from inspection of the data.

The "Baron" task (Baron, 1973; Baron & McKillop, 1975) studied by Rose and Fernandes (1977) is one in which the subject must judge visually presented sentences or phrases as "sense" or "nonsense" depending on instructional condition. In the SH (sense-homophone) condition, a phrase like "It's knot so" is to be regarded as "nonsense" because it is incorrectly spelled. In the HN (homophone-nonsense) condition such a phrase is to be considered as "sense" because it makes sense when spoken, as opposed to a sentence like "The knife is pull." In the SN (sense-nonsense) condition, a sentence like "Please cash my check" is "sense" and one like "A deck of carts" is to be regarded as "nonsense." In any block of trials, "sense" and "nonsense" stimuli appear with equal frequencies. The basic data are mean RTs (by key press) for each phrase type (S, H, N) as a function of condition, and are combined to generate overall condition times (SN, SH, and HN). These latter variables were used in our factor analysis of Rose and Fernandes' correlation matrices for Day 1 and Day 2. The ratio of SH time to HN time, presumed to provide a basis for classifying subjects as "visual" (low ratio) or "phonemic" (high ratio) in their approach to word encoding was not used in the factor analysis because of its dependence on the basic variables; also, it exhibited few significant correlations with other variables in the matrix, perhaps because none of the other tasks was designed to measure differences in visual vs.

phonemic encoding. Distributional statistics on the RTs for SN, SH, and HN times are as follows:

	SN		SH		HN	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
Mean (msec)	1205	1193	1289	1187	1579	1423
Median	1172	1181	1250	1165	1558	1450
Standard deviation	246	197	300	241	306	235
Reliability	.83		.90		.47	

Significant Day 1 - Day 2 practice effects were reported for the variables SH and HN, but not for SN. The SH and SN measures appeared with strong factor loadings on factor ROFE-B on both Day 1 and Day 2; the third variable (HN) had loadings of .47 and .56 on this factor on the two days, respectively; perhaps these lower loadings reflect the variable's lower reliability. We interpret factor ROFE-B as measuring Speed of Semantic Decisions, but its involvement with reading speed and general verbal ability should be considered as a possible aspect of its interpretation. In future studies, any variance reflected in the ratio variable SH/HN would have to be investigated in conjunction with other tasks designed to measure visual vs. phonemic word decoding, such as those used by Frederiksen (1978). The variance of this variable was small (S.D. = .09) and it had a reliability of only .37. Note that none of the variables SN, SH, or HN loaded on factor ROFE-A that we interpret as Speed of Mental Comparisons.

ECTs Classified Under Paradigm 4 (Stimulus Matching/Comparison)

This category contains a large number of ECTs that have received detailed attention in experimental cognitive psychology in recent years. It includes, for example, the so-called "Posner" letter-matching task (Posner & Mitchell, 1967), the "Sternberg" STM-memory search task (Sternberg, 1966, 1975), and the Clark and Chase (1972) sentence verification task. These tasks, and ones like them, occur in numerous variants, and IDs in their performance have received extensive though hardly exhaustive treatment. For convenience in our discussion of them, they are taken up according to the presumed kind of memory from which the compared representations are drawn, and according to the types of contents that are compared. Attention is also paid to certain variations in experimental procedure that may possibly show influences on results, for example, the simultaneous vs. successive presentation of stimuli to be compared or of stimuli constituting the memory set in the Sternberg task.

The largest category of these tasks is comprised by those that require comparison, in immediate working memory, of pairs of stimuli that are presented either simultaneously or successively. The Posner task and its variants are included in this category. Another relatively large category includes tasks, such as the Sternberg task, that involve entry of a series of stimuli into short-term memory and subsequent comparison of a "probe" stimulus with the contents of working memory. Further tasks can be classified as those involving recognition of stimuli presented to immediate memory that have also been entered into memory over a somewhat longer period, even those residing in "long-term" memory.

It is noteworthy that the stimuli involved in ECTs classified here are almost exclusively visual (except in certain variants of the Sternberg task). The realm of auditory stimulus comparisons seems to be virtually unexplored from an ID standpoint.

The several ECTs considered here have been used to address various issues in cognitive psychology, e.g., in the Sternberg task the question of serial vs. parallel processing, and in the Clark and Chase task the processes involved in sentence comprehension. We shall omit discussion of such questions except as they pertain to matters of IDs in performance.

Comparisons of Visual Shapes (Including Letters) for Physical Identity

Use of the Posner task has figured prominently in the literature concerned with relations between simple cognitive performances and "psychometrically" defined "intelligence," "verbal ability," and "reading ability" (Hunt, 1978; Hunt, Lunneborg, & Lewis, 1975; Keating & Bobbitt, 1978; Jackson & McClelland, 1979). (We place these terms in quotation marks to signify concern as to their exact meanings.) The Posner task typically calls for same-different judgments about visually presented alphabet letters; the letters are either in the same case (upper or lower), or in different cases; the instructions are either to compare the letters for "physical" identity or to compare them for "name" identity (same letter, regardless of case). Obviously, comparison for physical identity can be done without reference to the names of the letters; in fact, this part of the task could be performed readily by individuals with no familiarity with the Roman alphabet, but a question as to how familiarity with the Roman alphabet may influence physical identity judgments can still arise. (Research not concerned with IDs has sometimes utilized comparisons of letters in alphabets that are unfamiliar to the subjects; Posner & Mitchell, 1967.) More generally, one can inquire what abilities are involved in judging identities of shapes of any type, considering letters of the alphabet, or letter strings (words, pseudowords, etc.) as special cases, without regard to the possibly independent abilities involved in accessing symbol-codes in long-term memory. The existence of such abilities is a separate problem, addressed below. On the other hand, neuropsychological evidence may argue against considering shape comparisons and symbolic letter-comparisons in the same category.

From the perspective of this review, the data available for drawing conclusions about visual comparison abilities are extremely fragmented and incomplete. Even to assemble consistent and reliable information about the central tendencies and variances for "same" and "different" RTs for normal adult subjects is virtually impossible, to say nothing of relating these differences to performance on other ECTs or on psychometric tests.

We have not delved into what is undoubtedly an extensive literature on shape-similarity judgment (a literature that generally ignores IDs) but some information is available from the literature surveyed here. To get an impression of the degree to which the nature of the visual shapes being compared may influence same/different IDs, we array a number of results in Table 4 according to increasing mean or median RT for "same" judgments or for "same" and "different" judgments combined. (Many authors combine data for "same" and "different" judgments because the same effects are observed with the two types of data. We feel that it would be desirable to consider them

Table 4

Reaction Times to Physically-Identical Stimuli Compared for Physical (Name) Identity

#*	Study	Task (items compared)	Instr-uction	Group or Occasion	Est. Vis. Angle	Simul. or Successive Present'n	Mean or Median Reaction Time		
							"Same"	Combined	"Diff."
	Cooper (1976)	Shapes	Phys.	Type I subjects	2°	Succ.	365	--	425
(1)	Wingfield (1968)	Pictures	Phys.		6°	Succ.	--	450	--
	Jackson & McClelland (1979)	Simple patterns	Phys.	Fast readers	.57°	Simul.	450	--	469
(2)	Hock, Gordon, & Gold (1975)	Letters	Phys.	"Structural Ss"	.75°	Simul.	443	--	--
(3)	Jackson & McClelland (1979)	Letters	Name	Fast readers	.57°	Simul.	492	--	592
	Jackson & McClelland	Simple patterns	Phys.	Aver. readers	.57°	Simul.	506	--	532
(4)	Hock, Throckmorton & Colombo (1976)	Words (same case)	Name		.75°	Simul.	521	--	--
(5)	Hunt, Lunneborg & Lewis (1975)	Letters	Name	High verbal	?	Simul.	524.5	--	--
(6)	" " "	Letters	Name	Low verbal	?	Simul.	542.8	--	--
(7)	Rose & Fernandes (1977)	Letters	Phys.	Day 2	?	Simul.	547	--	693
(8)	Jackson & McClelland	Letters	Name	Aver. readers	.57°	Simul.	558	--	690
	Allen, Rose & Kramer (1978)	Letters	Phys.	Day 2	.3°	Simul.	--	580	--
(9)	Rose & Fernandes (1977)	Letters	Phys.	Day 1	?	Simul.	585	--	761
(10)	Keating & Bobbitt (1978)	Letters	Phys.	High ability Age 17	?	Simul.	--	586	--
(11)	Bisanz, Danner & Resnick (1979)	Pictures	Phys.	19-yr-olds	7°	Simul.	589	--	607
(12)	Hock, Gordon & Gold (1975)	Letters	Phys.	"Analytic Ss"	.75°	Simul.	591	--	--
	Cooper (1976)	Shapes	Phys.	Type 2 Ss	2°	Succ.	640	--	600-785
(13)	Keating & Bobbitt (1978)	Letters	Phys.	Aver. ability Age 17	?	Simul.	--	643	--
(14)	Hunt, Lunneborg & Lewis	Letters (card sort)	Phys.	High verbal	?	Simul.	--	684	--
	Allen, Rose & Kramer (1978)	Letters	Phys.	Day 1	.3°	Simul.	--	710	--
(15)	Hunt, Lunneborg & Lewis	Letters (card sort)	Phys.	Low verbal	?	Simul.	--	717	--
(16)	Goldberg, Schwartz & Stewart (1977)	Words	Phys.	High verbal	?	Simul.	--	732.8	--
(17)	" "	Words	Phys.	Low verbal	?	Simul.	--	868.7	--
	Jackson & McClelland	Dot patterns	Phys.	Average readers	.9°	Simul.	--	1230	--
	" " "	Dot patterns	Phys.	Fast readers	.9°	Simul.	--	1256	--

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*Numbers indicating match with data sets in Table 5.

separately if only because there are systematic differences between "same" and "different" RTs.) It may be assumed that the data are always exclusively for correct judgments. In all cases, RTs include both decision and movement times; we have not found studies of the Posner task that distinguish these times. All data are for "adult" groups (age 17 and up); they include results for the Posner task in the physical identity instruction condition, and for the name-identity instruction when the stimuli are actually the same physically, because there is some evidence (Bisanz, Danner, & Resnick, 1979; Hock, Gordon, & Gold, 1975) that at least some subjects do not utilize name codes in judging physical identity of letters. The table does not include data for shape comparisons with rotation. Data on the visual angles subtended by items compared are given where readily available, because of the possible importance of this variable; in most other cases, indicated with a question mark, the visual angles are probably less than 1°, as where characters are presented with commercially available CRT screens.

In interpreting the results, it may be useful to pay some attention to whether the presentation of the paired stimuli is simultaneous or successive. In simultaneous presentation (side by side, or one above the other, as occurs in most of the studies) the RT must include time for encoding both the first and the second stimulus. With successive presentation (with or without an ISI) the RT includes little or no time of encoding the first-presented stimulus, and could be expected to be somewhat shorter, on the average, than that for a comparable simultaneous presentation; data in the literature seem to confirm this expectation (see Posner, 1978). On the other hand, immediately successive presentation of visual stimuli in frames similarly centered might introduce the problem that differences in shapes would be detected on the basis of noticing changes in some part of the visual field. Also, differences in physical- and name-identity judgments tend to decrease as the ISI between successive stimuli increases (Posner, 1978, p. 45). Just what procedure of presentation would be optimal for measuring individual differences in shape-identity judgments (or in name-identity judgments, for that matter) is at present undetermined.

The other major problem raised by consideration of Table 4 is the evidence that there may be radical and qualitative differences between subjects in their modes of comparing visual stimuli. Cooper (1976; Cooper & Podgorny, 1976) has identified two types of subjects: one group who appear to make fast, "holistic" judgments and whose RTs are minimally affected by the degree of dissimilarity between paired stimuli, and another group who make slow "analytic" judgments and whose RTs decrease systematically with increasing dissimilarity. A somewhat similar, but not necessarily identical, group difference is suggested by the work of Hock and his associates (Hock, 1973; Hock & Ross, 1975; Hock & Whitehurst, 1975; Hock, Gordon, & Whitehurst, 1974; Hock, Gordon, & Gold, 1975; Hock, Gordon, & Marcus, 1974; Hock & Marcus, 1976), who distinguish "structural" and "analytic" perceivers on the basis of the amount that their RTs are affected by figural asymmetry or by 180° rotation of figures. Since neither Cooper nor Hock has as yet used independent measures of these group contrasts it is at this time impossible to say whether they correspond to contrasts that might be established by conventional psychometric tests.

From Table 4 it may be seen that mean or median RTs increase as certain properties of the stimuli change. At first glance, it would seem that pairs of simple shapes or pictures of common objects are compared fastest; letters are compared more slowly, on the average. But letters are most often presented with a much smaller visual angle (e.g., on a computer screen, or in print) than shapes and pictures, and visual angle would be expected to influence recognition accuracy (Purcell, Stanovich, & Spector, 1978). (This would also implicate the subject's visual acuity or correction therefor.) The effect of visual angle and related variables, however, has not been investigated or controlled in the studies surveyed here. RTs also seem to be a function of type of group (High/Low Verbal, fast/slow readers, "structural" or "holistic" and "analytic" perceivers, by either Hock's or Cooper's classifications). Hunt (Hunt, Lunneborg, & Lewis, 1975) reported that high and low verbal subjects did not differ significantly in speed of judging two letters as physically identical, even though there was a trend (12 msec) favoring the high verbals. Jackson and McClelland (1979, Table 3), however, report significant differences with respect to reading ability (which is undoubtedly correlated with verbal ability as measured by Hunt), both for their "simple pattern" (+'s and O's) matches and letters. Fast and slow readers did not, however, differ significantly on their dot-pattern matching task, thus ruling out the possibility that on other, less complex matching tasks fast and average readers differ because of the sheer amount of information to be processed. We will return to this matter, and related issues, after we consider same-different judgments of pictures and symbols that can appear in different shapes, but with the same name.

Some further data on variances and correlations of visual shape comparison performances (still excluding those involving rotation) may be given at this point. The correlation between measures of RT and accuracy on Jackson and McClelland's (1979) Dot-Pattern matching task was -.71, suggesting that a speed-accuracy tradeoff function was responsible for much of the variance on this test. These authors discuss the possibility that speed-accuracy tradeoffs may have affected their other results, but in the end reject it because fast and slow readers did not appear to have different standards of accuracy. Scores on their Simple Pattern matching test (with pairs of +'s and O's) had the highest loading on our factor JAMB-A, along with scores on various other simple matching tests; we interpret this factor as Speed in Mental Comparisons.

Cory, Rimland, and Bryson's (1977) Comparing Figures test had a loading of .39 on factor CORB-C, which we interpret as Perceptual Speed. The self-paced section of the test had little correlation (.33) with the machine-paced version, probably because of low variance and low reliability; the machine-paced version appeared to be a better measure of Perceptual Speed, in view of the pattern of its correlations with other tests of that factor. One would expect a machine-paced format to emphasize speed of scanning and accurately comparing groups of figural shapes better than a self-paced version, but this would not necessarily imply that Perceptual Speed is associated with, or identical with, Speed of Mental Comparisons when those speeds are measured on an item-by-item basis in a laboratory setting. Perceptual Speed tests usually emphasize a visual scanning or search process over a series of stimuli, and they would not likely be implicated in single-item laboratory tests.

Allen, Rose, and Kramer (1978) studied the Posner task only for the physical match condition; the RTs had high loadings on factor ALRK-A, interpreted as Speed of Mental Comparisons.

From the limited amount of evidence thus far available, it appears that individual differences in speed of comparing visual stimuli for physical identity can be interpreted as reflecting a factor of Speed of Visual Mental Comparisons. The status of this factor relative to other kinds of speed factors in cognitive performance is as yet very unclear.

Error rates in visual comparisons, at least simple ones, are generally very low, and the literature surveyed yields little or no information about the relation of accuracy scores to other kinds of IDs.

Comparisons of Visual Shapes for Identical Values or Classifications

Characteristic of the Posner task is the use of a "name identity" condition in which two shapes that may be physically different are compared for identical symbolic values. Usually, the shapes are alphabetic letters, occurring in either upper or lower case, but Bisanz, Danner, and Resnick (1979) have introduced a task in which the stimuli are pictures of the same thing in different aspects (e.g., an open and a closed umbrella). Table 5 arrays what "normative" data seem to be available concerning the speeds of such comparisons when the stimuli are physically not identical. The basic question that will be addressed in this section, however, is whether IDs in comparing visual shapes for identical symbolic values are distinguishable, from a correlational standpoint, from IDs in comparisons of shapes for physical identity. In theory, and logically, comparison of shapes for identical symbolic values involves an additional cognitive process, that of finding the name codes for the shapes being compared. It is conceivable that there are individual differences in rates and amounts of success in finding such name codes, independent of rates and amounts of success in performing whatever mental comparisons are involved.

If we compare corresponding data in Tables 4 and 5 (using the numbers assigned to indicate comparable data sets), mean or median RTs for comparisons for identical symbolic values or classifications of non-physically identical are always larger (slower) than for

Table 5

Reaction Times to Non-Physically-Identical Stimuli Compared for Identical Symbolic or Categoric Value

#*	Study	Task (items compared)	Instr-uction	Group or Occasion	Est. Vis. Angle	Simul. or Successive Present'n	Mean or Median Reaction Time "Same"	Combined	"Diff."
(1)	Wingfield (1968)	Name-picture	Name		6°	Succ.	501.5	513	524
(2)	Hock,Gordon,Gold(1975)	Letters	Name	"Structural Ss"	$.75^{\circ}$	Simul.	552	--	--
(3)	Jackson & McClelland(1979)	Letters	Name	Fast readers	$.57^{\circ}$	Simul.	581	--	592
(4)	Hock,Throckmorton,Colombo (1976)	Words,mixed cases	Name		$.75^{\circ}$	Simul.	583	--	--
(5)	Hunt,Lunneborg,Lewis(1975)	Letters	Name	High verbal	?	Simul.	588.1	--	--
	Hogaboam,Pellegrino(1978)	Category word-picture	Instance		?	Succ.	601	638	678
(7)	Rose & Fernandes(1977)	Letters	Name	Day 2	?	Simul.	629	--	693
(6)	Hunt,Lunneborg,Lewis(1975)	Letters	Name	Low verbal	?	Simul.	631.7	--	--
(10)	Keating & Bobbitt (1978)	Letters	Name	High ability Age 17	?	Simul.	--	643	--
	Hogaboam,Pellegrino(1978)	Category word-Instance word	Instance		?	Succ.	652	677	700
(9)	Rose & Fernandes(1977)	Letters	Name	Day 1	?	Simul.	684	--	761
(8)	Jackson,McClelland(1979)	Letters	Name	Average readers	$.57^{\circ}$	Simul.	698	--	690
(11)	Bisanz,Danner,Resnick(1979)	Pictures	Name		7°	Simul.	697	--	687
(14)	Hunt,Lunneborg,Lewis(1975)	Letters (card sort)	Name	High verbal	?	Simul.	--	737	--
(12)	Hock,Gordon,Gold(1975)	Letters	Name	"Analytic Ss"	$.75^{\circ}$	Simul.	748	--	--
	Rose & Fernandes(1977)	Letters	Vowel cat.	Day 2	?	Simul.	771	--	693
(13)	Keating,Bobbitt(1978)	Letters(card sort)	Name	Aver.ability Age 17	?	Simul.	--	786	--
	Jackson,McClelland(1979)	Words	Meaning	Fast readers	$.57^{\circ}$	Simul.	788	--	855
(15)	Hunt,Lunneborg,Lewis(1975)	Letters (card sort)	Name	Low verbal	?	Simul.	--	803	--
(16a)	Goldberg,Schwartz, & Stewart (1977)	Homophone words	Pron.	High verbal	?	Simul.	--	806.3	--
	Rose,Fernandes(1977)	Letters	Vowel Cat.	Day 1	?	Simul.	849	--	761
	Jackson,McClelland(1979)	Homophones	Pron.	Fast readers	$.57^{\circ}$	Simul.	861	--	1106
(16b)	Goldberg,Schwartz, & Stewart (1977)	Category-instance	Instance	High verbal	?	Simul.	--	907.4	--
	Jackson,McClelland(1979)	Words	Meaning	Aver. readers	$.57^{\circ}$	Simul.	927	--	1055
	" " "	Homophones	Pron.	Aver. readers	$.57^{\circ}$	Simul.	1019	--	1245
(17a)	Goldberg,Schwart, & Stewart (1977)	Homophones	Pron.	Low verbal	?	Simul.	--	1168.7	--
	Jackson,McClelland(1979)	Pseudowords	Pron.	Fast readers	$.57^{\circ}$	Simul.	--	1221	--
(17b)	Goldberg,Schwartz, & Stewart (1977)	Category-instance	Instance	Low verbal	?	Simul.	--	1267.3	--
	Jackson,McClelland(1979)	Pseudowords	Pron.	Aver. readers	$.57^{\circ}$	Simul.	--	1365	--

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*Numbers indicating match with data sets in Table 4.

comparisons for identical physical shape. This fact supports the hypothesis that the former comparison involves one or more additional processing steps as compared to the latter, but it does not tell us anything about the character or number of these additional steps, or whether they proceed in parallel or in serial with physical comparison processes. Also, the conclusion depends at least partly on the assumption that comparisons of physical shapes are less likely to involve use of name codes. One possibility is that when stimuli are perceived as having name codes, they are used even in comparison of physically identical stimuli, but since both stimuli evoke the same name code, the FICORP process that applies to one stimulus is the same as the one for the other, and thus needs to be operated only once (or perhaps twice, but in parallel). In contrast, where the stimuli are not physically identical, two FICORP processes must be operated, one for each stimulus. Another possibility to be considered is that subjects differ in the extent to which they use name codes in comparing physically identical stimuli.

Various models can be and have been proposed for the processing of comparisons involving physical codes, name codes, or both. Posner and Mitchell (1967) originally introduced a simple model in which accessing a physical code occurs in both physical and name matches, but accessing a name code occurs only in a name match task. One could also propose a model in which access of name codes is the same process as access of physical codes, but takes proportionally longer. Arguing against both of these models are various types of evidence that accessing of physical codes and of name codes can be manipulated independently. Posner (1978, p. 38) now favors a "horse race" model whereby the two types of process proceed in parallel, simultaneously; which one is first successful depends on parameters under the experimenter's control.

Some information about the nature of code-accessing processes is given by the magnitudes of the differences between physically identical matches and symbolic or categorical matches, but the data available to evaluate these differences are meager. Averaging over any separate groups represented in the data sets, and then over data sets, these differences are found as follows (data from Jackson and McClelland's, 1979, Homonym and Synonym matches are not included in these comparisons because they had no pure word matching task data to provide baseline information):

	msec		msec
Word names	62	Word pronunciations	187
Picture names	85	Word meaning categories	287
Letter names	97		

However, there is evidence that on an individual subject basis, these differences may be correlated with some kind of ability as measured by tests of intelligence, verbal ability, or reading ability. The first question that may be posed is: Do these differences arise solely from a correlation of general speed of processing with some component of the mental ability scores, or are the differences at least in part independent of speed of mental comparison (as measured in a purely physical match task)? That is, do the symbolic match tasks measure some aspect of IDs that is qualitatively different from speed of mental comparison? (A further question, considered later, has to do with what aspect of mental ability scores is associated with either physical or symbolic code accessing speeds.)

We have tried several approaches to answering this question. One approach is based on examination of certain comparative data plotted in Figure 8. This figure plots, for a number of data sets, the mean or median RTs for responding "same" (or in some cases, combined data for "same" and "different") to stimuli that are physically identical against similar RTs for responding to stimuli that are physically different but have the same symbolic or categoric values. Usually the former values are collected under physical-identity instructions, but not always. The latter values are collected in every case under instructions to respond on the basis of some specific type of identity other than physical (word-name, word-picture correspondence, letter name, same pronunciation, or same word category). The figure was constructed, in the first instance, to study the magnitude of the difference between physical-identity and symbolic identity RTs. As may be seen, the points follow a general trend in line with what has just been described. When, however, points from different parts of the same data set were connected, an interesting phenomenon was noted. When the points from different ability groups are connected, the resulting slopes are much higher than those of the general trend, and also those of

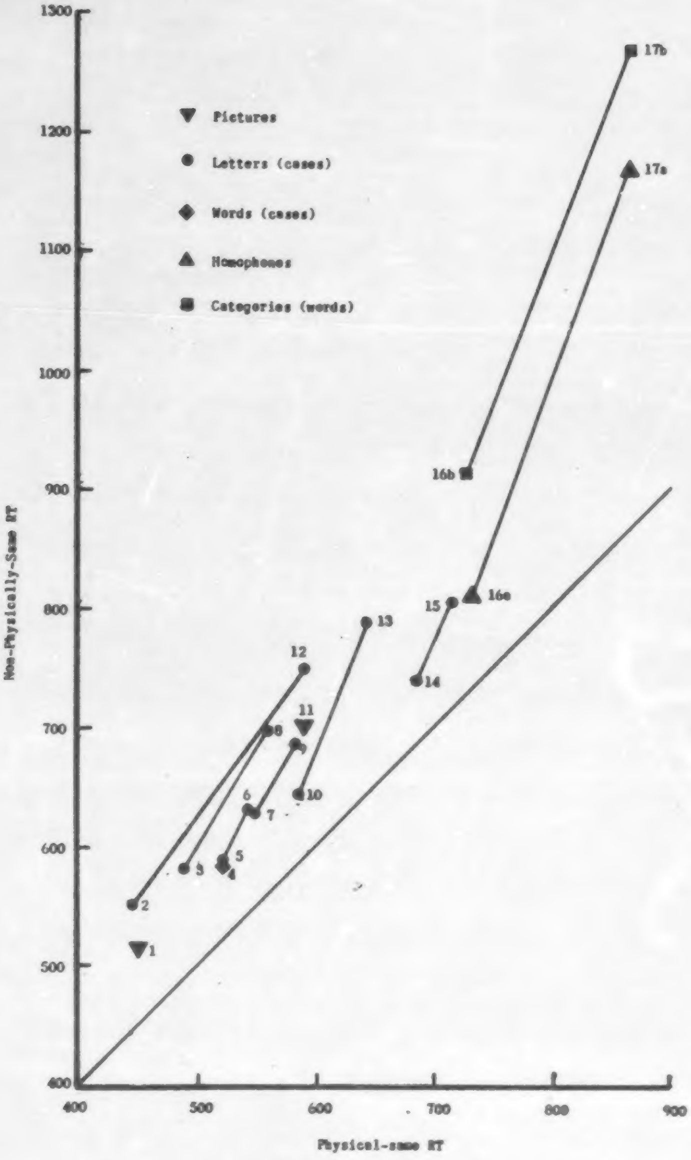

Fig. 8 Mean or Median RTs for "Same" Responses to Physically-Same Stimulus Pairs Plotted Against Those to Non-Physically Same Stimulus Pairs That Have the Same Symbolic or Categoric Value, from Several Data Sets (as Keyed by Numbers Corresponding to Those in Table 4 & 5)

two other data sets, one for a Day 2-Day 1 practice effect (from Rose & Fernandes, 1978) and one for a difference between "structural" and "analytic" subjects that may be considered as reflecting cognitive style or strategy differences rather than an ability difference. Specifically, the resulting slopes are as follows, first for six ability group comparisons and then for the two comparisons not involving ability:*

	Slope on Group Contrast
Goldberg, Schwartz, & Stewart (1977)	
Homophone task	2.67
Category task	2.64
Keating & Bobbitt (1978)	
Letter-match task	2.51
Hunt, Lunneborg, & Lewis (1975)	
Letter-match task (Computer version)	2.38
Letter-match task (Card-sorting version)	2.00
Jackson & McClelland (1979)	
Letter-match task	1.78
Rose & Fernandes (1977)	
Letter-match task, Day 1-Day 2	1.45
Hock, Gordon, & Gold (1975)	
Letter-match task, "Structural" vs. "Analytic" subjects	1.32

It should be noted that in every case, ability (and other) groups are differentiated on mean RT of the "same" response to physically identical stimuli. From evidence mentioned thus far, this is to say that "ability" is to some extent correlated with the factor interpreted as Speed of Mental Comparison. But if it were only correlated with that, the slopes of the lines connecting points for different ability groups would correspond to the general slope of the points in Figure 8 for any given task, i.e., it would be 1.00 or thereabouts. It appears that symbolic match times measure something in addition to speed of mental comparison, and the more complex the task (as in matching for homophones or meaning categories), the more it measures this additional factor.

A possible approach to understanding these findings is to consider the factor analysis that we have made of Jackson and McClelland's (1979) correlational analysis in their Table 5. One virtue in these results is that they allow us to consider data for certain tasks that could not be considered in the above analysis. A disadvantage is that they are based on a rather small N (24), but we are concerned only with the pattern of results, not with their exact values. For present purposes we use a graphically determined orthogonal rotation of four factors derived from Jackson and McClelland's data; the factor matrix is given in Table 6. The orthogonal solution is used here solely in order to simplify the handling of data in reproducing correlations. Equivalent results could be obtained, with a little more trouble, from the oblique solution, which we prefer, and which is given in Appendix A. Factor A is interpreted as Speed of Mental Comparisons; Factor B, as a Language Knowledge factor; Factor C, Perceptual Speed; and Factor D, Visual Sensory Threshold.

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*If one takes the Letter-Matching data as the baseline for Jackson and McClelland's (1979) Synonym and Homophone Match tasks, the slopes are 2.11 and 2.39, respectively, for the contrast between average and fast readers.

One important thing to notice about these results is that the reaction time tasks, loading on Factor A, had essentially zero loadings on the language knowledge Factor B, but most of the language knowledge variables had small to moderate loadings on the speed factor. One might have expected the reverse to be the case, on the supposition that the reaction time variables involved the same kind of accessing of letter and word codes that might be involved in reading, and that the language knowledge variables would not implicate speed of mental processing. A "Procrustes" analysis of these data embodying the latter hypotheses failed to produce a satisfactory simple structure.

Given the results as analyzed, we need to take another look at the situation. Note that it was the simplest types of RT variables that loaded highest on the RT factor A. The highest loading was for Physical-same letter match, a matching process that could, logically, be performed with no accessing of letter names. The Simple Pattern match had a loading almost as high--a variable in which only matches of "+'s" and "O's" were involved. As the task drew upon the more "difficult" types of matches--letter names, word meanings, and word pronunciations--the loadings decreased. (The findings are not dependent on differential reliabilities; according to Jackson [personal communication] the reliabilities are uniformly high.) These facts reinforce our belief that Factor A is a speed of processing variable that emphasizes simple, physical, visual comparisons. In fact, the more complex types of matches tended to have loadings on Factor C, which we

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Table 6

Graphically-Rotated Orthogonal Factor Matrix for Correlations in Jackson & McClelland's (1979) Table 5 (N = 24)

Variable No. & Symbol		Description	Factor Loadings A	B	C	D	h^2
9	PHY	Physical-same letter match	.94	-.06	.16	.11	.92
8	SLM	Simple pattern RT	.93	.00	.03	-.08	.87
10	NAM	Name-same letter match RT	.86	.06	.42	-.10	.92
11	SYN	Synonym match RT	.79	.10	.30	-.01	.73
12	HOM	Homonym match RT	.62	.02	.32	.07	.50
16	STM	Auditory letter span	.36	.26	.04	-.30	.29
2	SPEF	Short paragraph effective reading speed	.38	.85	.21	-.15	.94
1	LPEF	Long passage effective reading speed	.37	.82	.14	-.03	.83
3	LC	Listening comprehension	.22	.77	-.05	.22	.69
4	SCV	SCAT verbal aptitude	.20	.61	.24	-.01	.48
13	AHOM	Accuracy on homophone task	-.12	.61	.01	-.37	.53
15	Slp	Multiple display "slope"	.01	.01	.91	-.04	.83
14	MLD	Multiple display RT	.48	-.02	.79	.05	.86
5	SCM	SCAT quantitative aptitude	.23	.37	.52	-.10	.47
7	SLT	Single letter threshold	.07	-.31	.32	.67	.66
6	PSP	Peripheral letter span	-.08	.00	.11	.47	.23

interpret as Perceptual Speed or visual scanning. It is noteworthy that of these, the highest loading, .42., was for the name-same letter match RT.

The high slopes of name-identity matches on physical-identity matches by contrasting groups in Figure 8 would represent a high (negative) correlation of ability with a variable formed by subtracting physical-same match RT from name-same match RT. This is in fact the variable NI-PI used in Hunt's (1978) discussion of correlations between intelligence and cognitive processes. We can estimate the magnitude of this correlation from Jackson and McClelland's data, but only by making an estimate of the ratio of the respective standard deviations (not reported by Jackson & McClelland). On the assumption that this ratio is the same as the ratio of the physical-same mean RT difference (66 msec) for average vs. fast readers to that for name-same RTs (117 msec), the ratio of standard deviations may be estimated as 1 (for physical-same) to 1.77 (for name-same RTs). Applying a formula for the correlation of differences to the actual reported correlations, we estimate the correlation of variable 1 (long-passage effective reading speed), oriented to produce a positive correlation with a NI-PI variable (variable 10-variable 9), as .478. (The base correlations are $\underline{r}_{RN} = .45$, $\underline{r}_{RP} = .34$, and $\underline{r}_{PN} = .91$.) This is even higher, in absolute magnitude, than the .30 correlation regarded by Hunt (1978) as typically found. This correlation is a function of the factorial composition of the variables, and we can better understand it by examining how it could change as we vary factor loadings. We can approximately reproduce the relevant correlations by vector multiplication of rows in Table 8, giving reproduced correlations $\hat{\underline{r}}_{RN} = .43$, $\hat{\underline{r}}_{RP} = .31$, $\hat{\underline{r}}_{PN} = .85$. With the same estimated standard deviation ratio as before, these correlations yield $\hat{\underline{r}}_{R(N-P)} = .426$.

Now, considering the factor matrix data it can be shown that even if the loadings of the physical and name match variables on Factor B, and all loadings on Factors C and D, were assumed to be zero, the size of the NI-PI correlation depends critically not only on the respective variances of NI and PI but also on the loading of variable 1 on Factor A. As that loading increases from 0 to .5, for example, the NI-PI correlation with the ability variable (variable 1) increases linearly from 0 to .259. But the correlation can also increase with certain small changes of loadings of the NI and PI variables on Factor B, and to a lesser extent, on another factor, e.g. Factor C.

We can conclude, then, that a correlation between an "ability" variable and a NI-PI difference variable can arise when the ability variable has a significant loading on a speed of processing factor, that is measured by both the PI and the NI variables, and/or when these variables have slightly different factor compositions either on an ability factor or some other factor. In the Jackson-McClelland data, the loading of the NI variable on the Perceptual Speed factor C has a considerable effect, along with the effect of the loading of variable 1 on Factor A. When an ability variable has a substantial loading on a speed of processing factor, one may suspect that the ability variable has a speed component. Obviously, variable 1, derived from both speed and comprehension aspects of reading, has a speed component, as do some of the other variables loading on Factor B. The estimated NI-PI vs. ability correlations for those other variables are as follows (using Jackson & McClelland's actual reported correlations):

Variable 2:	Short passage effective reading speed	.573
Variable 4:	SCAT Verbal aptitude	.450
Variable 5:	SCAT Quantitative aptitude	.435
Variable 3:	Listening comprehension	.148

Variable 2 seems even more affected by speed than variable 1, and has a higher NI-PI correlation. The results for the two SCAT variables are probably explicable on the basis that nearly all commonly administered aptitude tests including, for example, the Washington Pre-College test used in Hunt's research, have at least some speed component because of time-limits imposed, even though the test constructors try to make the time-limits long enough to allow "most" (e.g., 90%) to try every item. This speed component could reflect either speed of reading, speed of information-processing (independent of reading speed), or both. The low and probably insignificant NI-PI correlation for variable 3, listening comprehension, seems to indicate that this variable, at least, was not speeded either by design or in actuality. It would have been interesting for Jackson and McClelland to have presented results for their reading speed and comprehension variables separately; our speculation would be that the NI-PI correlation would be high for the former and very low or zero for the latter.

From this analysis, it appears that speed in matching stimuli for symbolic codes reflects some ID dimension over and above the speed of mental comparison factor that is measured by physical-similarity matches. This further ID dimension, however, is not associated with verbal ability or language comprehension as such, but with some kind of perceptual speed ability that is incidentally measured, to some small extent, by typical tests of intelligence, verbal ability, scholastic aptitude, or reading ability. Whether this latter ability is of any importance in predicting scholastic achievement is unclear; this is in any event a separate issue that cannot be considered here.

If indeed the NI-PI difference is important (theoretically or otherwise) as distinct from the separate variables that generate the difference, there is an empirical way of determining this. If the NI and PI RT variables are placed separately in a multiple regression solution for predicting some ability variable, and if the NI-PI difference is critical, NI and PI should each have a significant regression weight, and the weights should have opposite signs; ideally the raw score weights should be proportional to +1 and -1, respectively, if the NI-PI difference is to represent an actual processing time difference, independent of both NI and PI, that is to predict a negatively oriented external ability variable. Acting on this logic, one can use Jackson and McClelland's data to investigate the optimal weighting of NI and PI variables to predict several such external ability variables. The results are given below; they are based on the assumption, explained earlier, that the standard deviation of NI is 1.77 times the standard deviation of the PI variable. (This assumption, however, is not critical to the results, in the sense that it does not affect signs, multiple correlations, or significance levels. It is critical only to the relative magnitudes of the b-weights.) The entries in the columns for NI and PI are their raw-score regression weights (b) for predicting the external variables indicated in the respective rows. Further columns list the multiple correlations (R) and their significance levels (p). The significance levels for the b-weights are indicated with asterisks: (*) means $p < .05$; (**) means $p < .01$.

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External Variables (all negatively oriented)	b-weights NI	b-weights PI	R	p
Long paragraph effective reading speed	.46	-.40	.48	.06
Short paragraph effective reading speed	.65**	-.73	.58	.01
Listening comprehension	.08	.03	.17	.74
SCAT Verbal composite	.58*	-.75	.47	.07
SCAT Mathematical composite	.50	-.56	.44	.11

What is interesting about these results is that for all the external variables except Listening Comprehension, the b-weights for NI and PI are indeed approximately proportional to +1 and -1, respectively. Unfortunately, in no case are both of the b-weights statistically significant, as would be required by our logic. This is probably due to the low statistical power inherent in the small sample size. Nevertheless, the results suggest (but do not prove) that the NI-PI variable may have some independent validity.

This multiple regression analysis, incidentally, does not depend on any assumptions about the factorial composition of the variables; it utilizes all the covariance available, whether it be of a common factor or specific factor nature. At the same time, the analysis suggests, again, that the NI-PI variable is relevant only in predicting external variables that contain a speed component, and that it is not relevant in predicting variables measuring pure verbal knowledge or language comprehension. This statement does not exclude the possibility, indeed the probability, that the NI-PI variable, whatever it measures, is an important component of reading speed, as Jackson and McClelland (1979) argue.

Space does not permit a detailed examination of all the reports concerning NI-PI differences and the possible correlation of these differences with ability variables. There are a number of points to consider in assessing this literature; it is not known which if any of these points is critical:

1. The variables used, with regard to whether only RTs for "same" responses are utilized, in either physical or symbolic comparisons, as opposed to RTs for "different" responses, whether or not separately obtained under physical-identity and name- or symbol-identity instructions.

2. Whether non-linear (e.g. reciprocal or logarithmic) transformations of the RT variables would produce more significant results than the raw variables, and if so, what theoretical justifications could be advanced for such transformations.

3. Whether simultaneous or successive presentations of the paired stimuli are given. As may be seen from Tables 4 and 5, nearly all studies have utilized simultaneous presentations; Hunt, Frost, and Lunneborg's (1973) early study is one exception. Also pertinent here is the extent of any ISI inserted between successively presented stimuli. The extent and possibly the meaning of the NI-PI difference may change as the ISI varies (Posner, 1978, p. 45). Possibly Hogaboam and Pellegrino's (1978) failure to find a NI-PI correlation with SAT scores came about because their experimental procedure involved *in effect* successive rather than simultaneous presentation, with an indeterminate ISI. Their failure may also have come about because the first presentation was of a category name that, in effect, the subject did not have to retrieve for the comparison with a word or picture.

4. Whether decision time was measured separately from movement time. We have not found studies of the stimulus matching task that have distinguished these aspects of measured reaction time.

5. Considerations of visual angle and illumination of presentations. Acuity factors may be more critical for symbolic or category judgments than for physical matches, although it seems unlikely that acuity factors would be related to ability differences.

6. Most importantly, the possible involvement of a significant speed element, however small, in an "ability" variable that is correlated significantly with an NI-PI difference, where the speed component rather than any level of mastery component accounts for most or all of the covariance. This point implies that separate speed and level of mastery components in ability measurements must be identified and used as variables in future research.

Comparisons of Visual Shapes Involving Reflection or Rotation

Many psychometric measures of the factors Spatial Orientation and Spatial Visualization have employed tasks requiring the subject to "mentally" rotate or reflect a stimulus in order to make a comparison with some presented stimulus, or to recognize the orientation of a stimulus, but the dimensionality of these "spatial" abilities has never been very clear (Ekstrom, French, & Harman, 1979). These are complex tasks and it is possible that they draw upon a number of cognitive processes. The nature of these tasks might be clarified through experimental studies.

First indications that it might be possible to pin down parameters of spatial abilities through experimental investigation came through studies such as those of Cooper and Shepard (1973) and Shepard and Feng (1972). Cooper and Shepard's report includes separate functions for "fast" and "slow" subjects in the task of determining whether a letter (such as R) is presented in its normal form (R) or reflected (Я) after rotation through a given number of degrees. The interpretation was that subjects differed in the speed (degrees per second) with which they "mentally rotate" a stimulus. In their study, the average speed was about 482° per second with (what we would estimate as) a standard deviation of about 160° over subjects.

Tasks involving rotation or reflection have been investigated in a number of the studies surveyed here. Rose (1974) and Allen, Rose, and Kramer (1978) used a paper-and-pencil form of the Cooper-Shepard task. Rose established substantial reliabilities (.71, .74) for mean scores on his task; Allen, Rose, and Kramer found reliabilities (Day 1 vs. Day 2) of .64 for an intercept parameter and .75 for a slope parameter (both for scores that excluded errors). In our factor analyses of their data, however, the results are unclear, probably because there were not sufficient marker tests for the rotation parameters (intercept and slope). The mean score for Rose's test tended to correlate with simple reaction time. In Allen, Rose, and Kramer's study we found the intercept of the RT/rotation function correlating primarily with sentence recognition and recall scores on Day 1 (Factor ALRK-D), but not on Day 2. The slope parameter correlated with variables measuring Speed of Mental Comparisons (factor ALRK-A), again only on Day 1. The communalities of both parameters on Day 2 were very low, possibly because (as Rose suggests) subjects did not really learn to perform the task properly until Day 2; on Day 2, therefore, their performance was no longer affected by simple reaction time processing speeds.

The rotated/reflected letters task has also been studied by Hock and his associates (Hock, Gordon, & Gold, 1975; Hock, Gordon, & Marcus, 1974; Hock & Marcus, 1976). They find that subjects differ in the extent to which their performance is affected by rotation, and use this difference to classify subjects as "analytic" (small effects) and "structural" (larger effects) and to make certain interpretations about the differential processes used by these subjects. In making comparisons, "analytic" subjects are thought to use verbal codes and local features of stimuli without actually doing mental rotation, while "structural" subjects would compare rotated images. Hock et al.'s results and interpretations should be considered in any further research on rotated-letter matches. Their research, even though based on small Ns, also suggests the importance of controlling letter-frequency in this area of experimentation, particularly for "analytic" subjects, because of their presumed use of verbal codes.

Egan (1978) investigated latencies and accuracies on experimental versions of certain spatial ability tests. The experimental versions involved binary decisions as to whether one visual representation was a correct rotation (through even 3 dimensions) of another. Two clear uncorrelated factors emerged--EGAN-A, which we interpret as Spatial Accuracy, and EGAN-B, Spatial Speed. Neither factor was correlated with factor EGAN-C which was loaded with tests of Numerical Operations and Verbal Comprehension. Egan's study did not contain data that would permit one to associate the speed factor with any other kind of speed factor, e.g. the Speed of Visual Mental Comparison factor that we have been postulating. The possible relationships should be investigated Egan's study, however, is important in showing that there are clearly separate speed and accuracy factors in the spatial domain--factors that have apparently not been adequately recognized in previous studies of spatial ability. A possible implication is that the lack of clarity in investigating the spatial ability domain has arisen in part from the failure to recognize the separate roles of speed and accuracy; the relative roles of these abilities may differ over different types of spatial ability tests.

Even after Egan's interesting study, and others mentioned here, the important question that remains is whether parameters of "mental rotation," that may apply at least to some groups of subjects, are specific to this kind of task or are related to any other, broader parameters of cognitive speed and accuracy. The data available thus far do not permit even a prediction, one way or the other.

The fact that there seem to be individual differences in speeds and modes of processing rotated and reflected stimuli needs to be taken account of in the interpretation and further pursuit of reading research like that of Kolers (1968). Posner, Lewis, and Conrad (1972) and Kolers (1972) have discussed the implications of Posner's findings for reading research.

Sentence Verification Tasks

Sentence verification tasks have figured prominently in psycholinguistic studies (e.g., Slobin, 1966; Clark & Chase, 1972). We classify them under Paradigm 4 because they often involve a comparison of a visual, pictorial presentation with a linguistic stimulus (a sentence or some approximation thereto) that may or may not represent, or correspond to, the visual presentation. In a sense, they represent an extension of the word-picture comparison task considered earlier. Usually, latency and accuracy measurements are taken to investigate detailed aspects of language comprehension, e.g., the influence of negation. It is only in recent years that the role of individual differences in these tasks has come under study. This area of investigation contains interesting questions because although the language materials that are used are generally well within the comprehension of the subjects, and the subjects may be assumed to have automatized their language comprehension skills over many years, there appear to be striking individual differences in the accuracy and particularly the speed with which subjects can perform different aspects of the sentence-verification task.

In the studies reported here, two types of sentence-verification tasks were employed. One was adapted from a "grammatical reasoning" test devised by Baddeley

(1968) requiring subjects to indicate whether a sentence like "A is not followed by B" accurately describes a letter sequence like "A B." The other was the task devised by Clark and Chase (1972) in which the subject has to decide whether a sentence like "Star is not above cross" (or "plus") accurately describes a visual presentation like $[\overset{+}{*}]$. The sentence can be varied in grammatical form using such transformations as active/passive, negation, linguistic markedness, etc., and Clark and Chase have proposed a model by which certain parameters can explain the effects, on latency measures, of such transformations. In most of the studies, the sentence and "picture" were presented simultaneously, and the latency measures did not distinguish among encoding, decision, and response times. Studies by Hunt, Lunneborg, and Lewis (1975) and MacLeod, Hunt, and Mathews (1978), however, employed successive presentation, the linguistic stimulus being presented first and an "encoding" latency being recorded before presentation of the "picture." This procedure has obvious advantages.

Some information about ID correlates of sentence-picture performance can be gleaned from those studies that utilized simultaneous presentation. Rose (1974) studied a pencil-and-paper form of Baddeley's task, the score being the number of items marked correctly in 1 minute. (Thus, speed and accuracy were confounded.) Test-retest reliabilities of this score were substantial (.70; .80), and the scores tended to correlate with subject-reported SAT (Scholastic Aptitude Test) scores. Rose and Fernandes (1977) gave a computerized version of the Clark and Chase task, the sentence on the left and the picture on the right of a display. Data were used to estimate Clark and Chase's four parameters. Test-retest reliabilities of two of these parameters, however, were extremely low: The parameter for the effect of linguistic markedness ("below" vs. "above") had a Day 1-Day 2 correlation of -.06, while that for "comparison" was only .28. Correlations for a "base" parameter (essentially, an initial intercept parameter) and for a "negation" parameter were .59 and .81 respectively. Some practice effects were observed. The parameters showed low intercorrelations on both Days 1 and 2, and our factor analytic results were not highly consistent over the two days. The fairly weak loadings (.30; .31) of the "base" parameter on factor ROFE-B (Speed of Semantic

Decisions) can perhaps be rationalized. The "negation" parameter was associated with Sternberg-task slopes (factor ROFE-D) on Day 1 and with various parameters of Juola Word and Category tasks on Day 2; the study yielded no information concerning relations with traditional psychometric tests. Lansman (1978) used a Clark and Chase task, with simultaneous presentation of sentence and picture, in a dual-task setting; factor analysis of her data yield two independent factors: an accuracy factor (LANB-C, Accuracy of Semantic Information Processing), and a speed factor (LANB-A, Speed of Semantic Information Processing) that is associated not only with latency variables under all conditions of her experiment but also with speed in doing three-term series problems and with scores on the Washington Pre-College verbal composite. (It is interesting that speed, not accuracy, was associated with this verbal ability measure. As is discussed later [p. 253], the interpretation of this finding depends upon the possible speededness of the WPC.)

As noted previously, two studies employed successive presentation. Hunt, Lunneborg, and Lewis (1975) reported that subjects with relatively lower verbal ability took significantly more time than "high verbals" to process negation, both in encoding and decision phases. No variable from this task, however, was included in their factor-analytic results. The nature of IDs that can be exhibited in the Clark and Chase task began to become clear, however, only with a detailed study by MacLeod, Hunt, and Mathews (1978). Space does not permit recounting all the interesting details from this study. Suffice it to state that the study showed, first, that subjects could be classified by their apparent strategy in performing the task. Data for the majority of subjects conformed to the theoretical performance model set forth by Clark and Chase whereby a conversion between sentence and picture would occur only after actual picture presentation (in the second phase of the task). Some subjects, however, apparently made a conversion from sentence to picture before the picture was itself observed; i.e., they "predicted" what the picture might look like in the first phase of the task and then evaluated their prediction in the second phase. The two groups of subjects differed little in verbal ability, but the second group was distinctly higher in spatial ability.

Further, partial correlation techniques indicated that the data of the first group were dependent almost exclusively on verbal ability, while the data of the second group were dependent almost exclusively on spatial ability. It was suggested that the subjects selected their strategies partly on the basis of their pattern of abilities.

Unfortunately, the verbal and spatial ability tests used by these investigators were not such as to permit further analysis or interpretation as to whether it was more the speed or the accuracy aspects of these abilities that accounted for the results. (An unspeeded form of the Nelson-Denny Reading Comprehension test was used but the report contains little analysis of the data from this test; we know only that verification RTs were correlated with Nelson-Denny scores -.47 in the first, "well-fit" group, and -.03 in the second, "poorly fit" group.)

Further work with IDs in sentence-verification tasks, then, would have to employ several variants of the task and as much statistical and/or experimental control as possible over subject strategies, along with a suitable range of external variables in verbal and spatial speed and accuracy by which to interpret results. It may also be suggested that more elaborate forms of sentence verification tasks could be investigated, since the grammatical transformations thus far used have been quite elementary.

Visual Search and Comparison Tasks

Visual comparison tasks classified under Paradigm 4 often involve a visual search and scanning process whereby the subject must survey (by eye movements or otherwise) a series of spatially separated stimuli. It can be claimed that such a search process is involved even in the Posner task when the paired stimuli are presented simultaneously, side by side or one above the other, and some support for this claim comes from the fact that in our factor analysis of Jackson and McClelland's data letter-, synonym-, and homonym-matches had small but possibly significant loadings on a factor we interpret as Perceptual Speed (factor JAMB-C), defined by two variables from a Multiple-Letter Display task in which the scanning process seems to have been particularly emphasized. In this task, the subject was given, in a half-second display that would certainly be adequate for apprehension and encoding, a single target letter, followed by a "search set" of

2, 4, or 6 letters arranged to be equidistant (at what visual angle, we are not told) from the fixation point where the target letter was presented. The subject's task was to report whether the target letter was in the search set. Exposure time for the search set was only 200 msec, again above threshold but extremely demanding in terms of any visual search processes. (This time would probably permit only about one eye movement; what eye movements may have occurred we are not told.) That this was *not* a sensory threshold task is suggested by the low correlations between a Peripheral Letter Span task and the two variables, RT and "slope" determined from the Multiple-Letter task, .01 and -.12 respectively. RT correlated .73 with slope on the MLD task. It would seem, intuitively, that performance was crucially dependent upon the subject's ability somehow to *search* the visual field rapidly, to detect the target letter. This is an ability that also seems to operate, although perhaps not quite so critically, in many psychometric tests, particularly those of the factor called Perceptual Speed (Ekstrom, French, & Harman, 1979, pp. 29-31). Typical tests of Perceptual Speed are Finding A's, in which the subject has to search a column to find words containing the letter *a*; Number Comparison, in which pairs of multi-digit numbers are to be checked for identity; and Identical Pictures, in which a "target" line-drawing is to be searched for in a set of five highly similar figures. Ekstrom, French, and Harman (1979), however, point out that the measurement and interpretation of the Perceptual Speed factor are by no means clear; they cite evidence for its possible multidimensionality.

In addition to the Jackson and McClelland study, other studies surveyed here provide evidence for some kind of perceptual speed factor, because they contain visual search tasks similar to the Multiple-Letter Display task. At a very crude level, Whitely's Response Decision task may be an example; in this task, the subject had only to search for the one of five alternative words in a multiple-choice-type item that was identical to the lead or "key" word. Love (1977) used Guilford's Perceptual Speed test (requiring multi-digit comparisons) and found correlations as high as .68 with other measures that might have called for visual search.

In the experimental tradition, the visual search task derives from the work of

Neisser (1967, pp. 66-71 and passim) who among other things was concerned to determine scanning rates in a visual search task that much resembles that of the Finding A's test used as a marker for Perceptual Speed. Rose (1974) and Allen, Rose, and Kramer (1978) investigated a paper-and-pencil form of the Neisser Search task that could involve more than one target, actually up to four, and in the latter case, "degraded" stimuli (printed, as it were, with "mutilated" type). One suspects that too much was attempted with all these variations, for the results were somewhat insecure. Nevertheless, reasonably high reliabilities were obtained by Rose for both a mean score and a "slope" that was a function of the size of the search set; and both studies found clear search set size effects. In our factor analyses of these sets of data, it was virtually impossible to be sure of the identity of the factors measured by variables from these tasks. In the Rose study, the mean score on Letter Search was associated on factor ROSE-B, with the slope variable from Fitts' Tapping task, a finding that suggested that performance depended to a large extent on hand movement control in marking the answer sheet; in the Allen, Rose, and Kramer study we choose to study only the intercept and slope variables from the degraded version of the Scan and Search task, and these variables, being highly correlated, defined a doublet factor that showed only very weak relations with any other variables studied. Further studies using variants of the Neisser search task would be well advised to explore relations with different kinds and formats of Perceptual Speed marker tests.

In the studies surveyed, the only experimentally rigorous exemplar of a Neisser visual search task is that investigated by Chiang and Atkinson (1976; see also Snow, Marshalek, & Lohman, 1976). In their version, in which displays and responses were implemented with a computer terminal, a target letter presented for 800 msec was followed, 2200 msec later, by a search set of one to five letters arrayed horizontally. Note that when the set size was 1, the task was equivalent to a pure visual comparison task (with successive presentation) similar to the Posner Physical-same task. The intercept of the RT/set-size function, which would be related to the RT in a Posner-type task, was highly correlated with the intercept of a Sternberg memory search task, but had a correlation of only -.286 with the slope of the visual search task. We believe the intercept measures a Speed of Mental Comparison factor, or at least some very uncomplicated speed of response factor. The slope of the RT/set-size function was, likewise, highly correlated with the slope of the Sternberg memory-search task, and appeared on a separate factor which had an appreciable loading, incidentally, for the Verbal score of the Scholastic Aptitude test. Because the slope function would reflect visual scanning speed (and perhaps also memory-scanning speed), there seems good reason to postulate that it represents perceptual speed.

Some useful parametric data from Chiang and Atkinson's report (which contains further details) are as follows:

	Mean RT	S.D.	Internal Reliability	Test-Retest Reliabilities	
				Day 1-2	Day 2-3
Intercept	472	83	.95	.70	.80
Slope	42	21	.91	.29	.70

The low Day 1-2 reliability and the higher Day 2-3 reliability suggest that the task does not produce effective and meaningful measures without considerable practice. It is striking that the slope and intercept variables in this study had an intercorrelation of only -.286, in contrast to the high correlations obtained in some other studies mentioned here. The difference is possibly due to the use of computerized testing as opposed to the use of pencil-and-paper formats. Yet, the high correlations between corresponding variables on the Visual and Memory search tasks in the Chiang and Atkinson study may possibly be inflated by the fact that these tasks were administered virtually in a "dual task" setting. Trial blocks consisted of short series of three types of tasks (visual search, memory search, and digit span) and the subject was cued as to the type of task at the outset of each trial. Such a procedure might have caused subjects to use highly similar strategies in the visual and memory search tasks, and the data suggest that indeed, visual search and short-term memory search are highly similar processes, if not actually identical.

The data leave one with the feeling that while there are strong suggestions that experimental versions of visual search tasks measure (at least in their slope variables) nearly the same thing as is measured by traditional Perceptual Speed tests, the connection, if it exists, needs to be very much clarified. The experimental versions, of course, facilitate the collection of precise data on visual search performances and the variables that affect them.

Short-Term Memory Search Tasks (the "Sternberg" Task)

The short-term memory search task developed originally by Sternberg (1966, 1969, 1975) can be viewed as the obverse of the Neisser visual search task. Whereas in the latter the subject is presented in advance with a "target" stimulus which is to be searched for later in a visual display, in the Sternberg task the display in which a target is to be searched for is presented in advance, and must be held in memory while that target (the "memory probe") is presented and "searched" for. We have classified it under Paradigm 4, even though it seems to make a greater demand on "short-term memory" than many other tasks under this paradigm, because it requires a comparison of two stimuli, namely, one of the stimuli held in memory and the probe stimulus. At the same time it seems to involve a search process--scanning or searching through the material held in memory. A critical element in the Sternberg task is the size of the memory set; typically, the time a subject takes to make a report is in part a linear function of the size of the memory set. On the average, positive reports take less time than negative reports; nevertheless, the positive report is still a function of set size, with generally the same slope parameter (time per item in the memory set) as that of negative reports. Early in the investigation of IDs in cognitive processes it appeared (Hunt, Frost, & Lunneborg, 1973) that there were considerable individual differences in these slope parameters and that such slope parameters might be indicants of the general efficiency of cognitive processing and related to scores on tests of general intelligence or scholastic aptitude.

In the studies surveyed here, there are no truly "standard" procedures for conducting the Sternberg task, and it is not clear to what extent procedural variations might affect the nature of the variables derived or the extent to which these variables might reflect individual differences in cognitive functions. Most of the procedural variations occur in the presentation of the memory set. Usually it is presented visually, in which case the presentation may be either simultaneous (a set of stimuli presented as a single visual array) or successive (stimuli presented one by one, in succession, usually at a single fixation point); sometimes the presentation is auditory, however, in which case it is inevitably successive. The size of the memory set can be either constant (at least within a block of trials) or varied (more or less randomly from trial to trial). Whether the presentation of the memory set is simultaneous or successive, the total duration of the presentation may be constant over different set sizes, or it may vary as a linear (or other) function of memory set size. In whatever manner the memory set is presented, the procedure has much in common with that of a memory span task, and at least some of the parameters of the memory span task may apply to the Sternberg task. It would seem that if the memory set size is large and the duration of presentation is too short for the individual's capacity to apprehend and store, the accuracy and speed of the response in the Sternberg task would reflect an individual's memory span. This problem can be largely avoided by using only correct responses in the scoring of performance and the derivation of parameters. But even this procedure cannot totally avoid the problem of chance guessing which can arise with the use of single digits or letters in the memory set; a priori, the guessing factor would decrease with memory set size, and might contribute to the determination of the slope parameter. (I.e., chance is less with 26 letters than with 10 digits.)

One of the few studies to use a presentation duration (3 seconds) that was constant over varying memory-set sizes (1 to 5) was that of Hunt, Frost, and Lunneborg (1973, pp. 104-106), who reported significantly different slopes for "high" (58 msec) and "low" (80 msec) verbal subjects ($\underline{N}$ = 8 in each case). One wonders whether these results were due to the use of the fixed presentation duration, which may have taxed the memory span capabilities of "low verbal" subjects; yet, errors were reported as averaging only about 3 percent. In a later study, Hunt, Lunneborg, and Lewis (1975,

p. 218) employed successive presentation of the memory set at the rate of 1.2 sec per item (letters), thus with total presentation duration that was proportional to set size (1 to 5). No correlations with verbal ability were reported; evidently the positive and negative slope values were at least moderately intercorrelated (as one would expect them to be) because they appeared together on factor HULL-C, associated with scores on a dichotic listening task--but not with scores from verbal aptitude tests nor with a score on a digit span task.

One other study using fixed presentation duration is that of Keating and Bobbitt (1978, p. 160); the memory set (regardless of size, varying over 1, 3, and 5 randomly) was presented for 4 sec, followed by an interstimulus interval of 4 sec and a probe digit. While there appeared to be large differences between "high ability" and "average ability" subjects at younger ages (9, 13), at age 17 the differences in slopes were small and apparently insignificant (62 for average ability, 59 msec for high ability). Ability was indexed by performance on an appropriate form of the Raven Progressive Matrices test.

An excellent experimental version of the task was studied by Chiang and Atkinson (1976, p. 663; see also Snow, Marshalek, & Lohman, 1976). The memory set (varying from 1 to 5 randomly) was presented on a computer terminal screen at the rate of 1 letter per second, followed by a probe letter after a 2-sec ISI. (One would suppose that the length of the ISI would affect the extent to which the subject could rehearse or otherwise encode the memory set.) For all subjects ($\underline{N}$ = 30), mean intercept was 483 msec (S.D. 102, values ranging from 301 to 774), and mean slope was 43 msec (S.D. 20, values ranging from 12 to 117); intercept and slope were correlated to the extent of only .107. While internal reliabilities were high (intercept, .96; slope, .89), test-retest reliability for slope was low from Day 1 to Day 2 (.28), reaching .78 for the Day 2-Day 3 correlation. As in the case of the Visual Search task studied by these investigators, it appears that the slope parameter does not attain high reliability until the subjects are well practiced. As previously noted, corresponding slope and intercept parameters for the Memory and Visual Search tasks were highly intercorrelated, while the correlations between slope and intercept parameters themselves were low--only .107 in the case of Memory Search task. The Verbal score of the Scholastic Aptitude test had a loading of .46 on the factor (CHAT-B) that was defined by the slope parameters from the Memory Search and Visual Search tasks.

A computerized version of the task was also investigated by Rose and Fernandes (1977, pp. 23-24 and elsewhere). The procedure involved simultaneous visual display of the memory set (digits), for a duration proportional to the set size, followed (apparently--the report is not specific) immediately by the probe digit. Data (in msec) are given for both positive and negative intercepts and slopes for Day 1 and Day 2, as follows:

		Day 1		Day 2		Reliability (Day 1-2)
		Mean	S.D.	Mean	S.D.	
Intercept	Positive	442	88	425	78	.52
	Negative	536	98	464	59	.51
Slope	Positive	75	32	49	21	.60
	Negative	48	28	47	15	.45

Significant ($\underline{p} < .05$) practice effects were cited (p. 53) only for Slope Positive and Intercept Negative. The test-retest reliabilities are not impressively high, to say the least; judging from Chiang and Atkinson's results, we may assume that they possibly attained satisfactory reliability only on Day 2. Our factor analysis of Rose and Fernandes' data showed that on both Day 1 and Day 2, the intercept variables were loaded on factor ROFE-B along with RT variables from the Posner task; the slope variables tended to define their own factor, ROFE-D. The factorial composition of all variables, and the factor intercorrelations, tended to change from Day 1 to Day 2, suggesting again that amount of practice influences what is measured by the task.

A paper-and-pencil format called Set Membership was devised by Allen, Rose, and Kramer (1978). Subjects were presented verbally (i.e. auditorily) with a memory set of 1, 2, 3, or 4 letters; they then worked down a column of letters, checking whether each letter was one of those heard. Different memory set sizes were used on each page, but 30 seconds were allowed for the response phase of each page. From these data, it was possible to estimate intercept and slope parameters (in msec), and reliabilities, as follows:

	Day 1		Day 2		Test-Retest Reliability*
	Mean	S.D.	Mean	S.D.	
Intercept	490	100	410	70	.79
Slope	60	30	70	30	.66

*These data are taken from the correlation matrix, Table 6, the data given on p. 57 of the report apparently being in error.

Despite the pencil-and-paper format, the parametric data are in general agreement with those from other studies. Also, parallel with other results, the intercept variable was associated with a Speed of Mental Comparison factor (ALRK-A). The slope variable, together with the intercept variable, defined its own factor, in view of intercorrelations of slope and intercept of -.29 on Day 1 and -.36 on Day 2. It should be noted, however, that the format was rather unusual in that after the presentation of a memory set, the subject made *repeated* evaluations of stimuli. At the bottom of each page, subjects were required to write down the memory set. Apparently the investigators wnated to insure that the subjects actually remembered the memory set for each phase of the task; no information is given about the accuracy of subjects' memories although it is reported that total errors during the task were approximately 2 percent.

Lunneborg (1977, Study 1) included a form of the Sternberg task in a battery of experimental cognitive tests; few details are given as to the exact procedure, except that 1 to 6 consonants (letters) were sequentially shown on a projection screen, followed by a single probe letter. The correlation of slope and intercept parameters was .39 (positive, in contrast to many other results). While the intercept parameter had significant and substantial (negative) correlations with a number of psychometric test scores (up to -.49 with a spatial ability test), the slope variable correlated with these scores very weakly (-.27 with Space, -.26 with Clerical Names). We can interpret the correlations for the intercept variable as reflecting the operation of a speed factor, but can make little of the data for the slope variable.

The study by Rose and Fernandes (1977) included two variants of the Sternberg task in an experimental cognitive performance battery. These variants derive from the work of Juola and Atkinson (1971) and involve the use of words and sets of category instance words rather than the letters and digits typical of the standard Sternberg task. While the study was able to replicate Juola and Atkinson's major findings, the individual difference results were unpromising. Day 1-Day 2 test-retest reliabilities were generally very low, particularly for the Word task; for the category task (where the subject had to report whether a given "probe word" was an instance of one to four categories specified in the memory set) only the Intercept Positive variable had a reliability as high as .68. The remaining reliabilities ranged from .00 to .46. There was evidence of considerable variation in subject strategies in handling the Category task, and the memory search seemed to be self-terminating rather than exhaustive, in many cases. In our factor analysis of these data, the variables from the Word and Category tasks tended to define various specific factors not associated with factors measured by other tasks in the battery; the Category Slope Positive, however, had a loading of .63, on Day 2, on factor ROFE-B which we have interpreted as Speed of Semantic Decisions. It appears that the Juola-Atkinson tasks would be useful in assessing cognitive functioning only if they are employed after subjects have had extensive practice with them. They may, however, measure important dimensions of IDs that are not tapped by the standard Sternberg task.

To summarize, the intercept parameter of the typical Sternberg task appears to measure a speed factor that appears in other simple cognitive tasks, but data are insufficient to permit drawing even tentative conclusions about what is measured by the slope parameter other than it is different from what is measured by the intercept parameter. It may relate to the conventional Perceptual Speed factor involving visual scanning; that is, "memory scanning" may have much in common with visual scanning. Procedural variations in the administration of the Sternberg task have been great and thus far constitute an obstacle to the interpretation of the results from the standpoint of IDs. Use of word or category tasks in the Sternberg paradigm appears to introduce complications that make scores on such tasks even more complex and multifactorial than those of the typical tasks employing digits or letters, but careful research with such tasks might be rewarding.

Miscellaneous Recognition Tasks Involving Intermediate or Long-Term Memory

Here we consider a variety of delayed recognition tasks in which some kind of response is required to a probe stimulus and where the response is logically dependent upon some kind of previous stimulus input that has occurred some considerable time previous to the presentation of the probe stimulus. Both the speed and the accuracy of such responses may be studied, but in most studies it is accuracy that is measured. By "some considerable time previous" we mean times that are likely to be measured in minutes, hours, or even longer intervals of time, in any event longer than a few seconds as has been the case of other tasks classified under Paradigm 4. The speed or accuracy of responses can thus depend upon the strength and character of memory traces from intermediate or long-term memory.

Simple delayed recognition tasks were studied by Robertson-Tchabo and Arenberg (1976, p. 78) and Hock, Throckmorton, and Colombo (1976). The first of these was a recognition test that followed a 12-word free-recall task after an interpolated task. Twenty-four words (12 from the free-recall task and 12 distractors) were read one at a time; the subject had to decide whether or not each word had been presented in the free-recall task. Probably the reliability of this test was very low due to its shortness and the guessing element; in our factor analysis of the data in the battery, the communality was low (.22) and the score had only a weak loading of .26 on factor ROBA-E that we interpret as "Primary Memory," following the authors. Hock, Throckmorton, and Colombo's recognition test consisted of 180 pairs of words (thus, it was a much longer and more reliable test), half of which had been used in a prior Posner-type task that involved both "real" words and "pseudowords." On the basis of performance in the Posner task, i.e. the difference between physical-same and name-match RTs, subjects were classified into two groups: those "inferred to verbally mediate physical matches of real words" through name codes (i.e., "analytic" subjects, as they were called in some of Hock's other studies), and those inferred to base comparison only on perceptual comparisons ("structural" subjects). The recognition test was a "surprise" test that followed the Posner task. "Analytic" subjects exhibited no difference in recognition accuracy between "real" words used in physical vs. name match trials, but increased accuracy for pseudowords. "Structural" subjects showed better recognition accuracy for both real words and pseudowords used in physical match trials than for words used in name match trials. The results were interpreted in terms of the extent to which the different types of subjects performed at different levels of processing, i.e. in decoding the pseudowords. This study contained no other measures by which subjects' abilities could be assessed; it is mentioned here only because it suggests an ID variable that might need to be attended to in recognition studies utilizing words.

The Running Recognition task originally studied by Shepard and Teghtsoonian (1961) was used in three investigations surveyed here. In Rose and Fernandes' (1977, pp. 29-30) version, subjects were asked to proceed at their own pace through a list of 101 three-digit numbers, judging whether each number had been seen before. Maximum time allowed for each binary response was 10 seconds. The second occurrences of stimuli had varying amounts of "lag" from their first occurrences, the lags ranging from 1 to 36, with 5 exemplars of each lag in a given list. Data were analyzed in terms of various parameters from Shepard and Teghtsoonian's mathematical formulation and from signal detection theory. Day 1-Day 2 reliabilities for all these parameters were generally quite low, and although they exhibited some significant correlations among themselves (probably because of experimental dependence) they had few significant correlations with any other task variables in Rose and Fernandes' performance battery. Consequently, none of the variables from the running recognition task was used in our factor analysis of their data. The poor showing of this task was very likely due to the use of 3-digit numbers, which might be difficult for most people to encode meaningfully in a brief time. Nevertheless, the mean proportion correct was .73, with a standard deviation of .07, on both days; the Day 1-2 reliability was .56. It is possible that the task tapped an ability that was neither well measured nor well represented in other tasks in the battery.

Only slightly more meaningful results were provided in a version of this task employing words, rather than numbers, used by Fernandes and Rose (1978, pp. 11-15). The structure of the task was virtually identical to that studied by Rose and Fernandes earlier, except that each word was exposed for only 3 seconds. The proportion correct averaged .80 and had a Day 1-Day 2 reliability of .82; some other parameters (proportions of hits and of false alarms) had respectable though not impressive reliabilities, but parameters from the mathematical function did not. In correlational analysis, proportion correct seemed to measure different things on the two days: On Day 1 it correlated mainly with free recall measures, while on Day 2 it correlated more with several variables measuring memory span, resistance to interference, and sensitivity to "situational frequency" (see below).

A Running Recognition task was also studied by Underwood, Boruch, and Malmi (1978, p. 403). The stimuli were words, selected and arranged in the lists so as to detect the possible effects of associations and homophonic relations among items. Any such effects observed did not appear to be consistent; the authors concluded that subjects "in some way learned to control the tendency to produce false alarms to the associated items." There was evidence for considerable reliability (in the range .77 to .79) of measures of tendency to produce false alarms, but the reliability of a "basic measure" of running recognition ability was only .70. Both in the authors' own factor analysis, and in our oblique rotation of the results, the basic measure appeared with a fairly strong loading on factor UNBM-D, which we have interpreted (Chapter 3) as Recognition Memory for Episodic Events. At the same time, our orthogonalized analysis gives Running Recognition a fairly substantial loading on a general episodic memory factor.

Both Fernandes and Rose (1978) and Underwood, Boruch, and Malmi (1978) studied a so-called Situational Frequency task in which subjects were shown a list of 92 relatively uncommon (T-L frequencies 1 to 10 per million) words at 2 sec per word; the lists contained only 40 different two-syllable words, each presented either once, twice, three times, or five times. In a recognition test presented immediately afterwards, the subject had to make absolute judgments of the frequency with which each of the 40 words, plus 12 new words, had been presented; the score was the correlation of the subject's judgments with the actual frequencies, converted by a _z_-transformation. In Underwood et al.'s report, the mean correlations for two such tasks were .87 and .85, but in terms of _z_-transformations these values were 1.32 (S.D. = .30) and 1.26 (S.D. = .40), with a reliability of .67 (whether this was a "boosted" reliability is not specified). Thus, subjects can do quite well on this task, but differ appreciably. Very similar results were obtained by Fernandes and Rose, the lists and procedures being virtually identical to those used by Underwood et al.; these authors report Day 1-Day 2 reliabilities of .69 for the correlation between actual and judged frequencies and .82 for a regression or slope function that would also reflect tendency to under- or over-judge at different frequencies. In our factor analyses of both the Underwood et al. and the Fernandes and Rose data, the Situational Frequency variables tended to be associated with other recognition task measures. In the former data set, the basic Running Recognition measure appeared on factor UNBM-D, which, as just noted, is interpreted as Recognition Memory for Episodic Events, reflecting differences in people's sensitivity to the occurrence of events in the immediate past, including their frequencies. One may only speculate whether this factor is specifically associated with recognition of words as opposed to other kinds of events (e.g., pictures), and whether the factor composition would change if words of different frequencies and other attributes were used. Since only scores for accuracy have been used in the studies thus far, nothing is known about the possible characteristics and factorial composition of speed of response measures on these tasks.

Underwood et al. (1978) included in their study two other variables that are of possible interest here. These were derived from their "Simultaneous Acquisition" task in which subjects were shown slides depicting an imaginary drive through an urban area. One of the variables came from the fact that state names were seen with varying frequency on license plates. After the presentation, subjects were asked to judge the absolute frequencies of these names; their scores were computed as z-transformed correlations between judged and true frequencies (10 state names having frequencies of 1, 3, 6, 10, or 15). On trial 1, mean score was 1.30 (S.D. = .50), and on trial 2, it was 1.23 (S.D. = .49); intertrial reliability was .59. The variable had no significant correlations with other variables in the battery and was not included in their factor analysis. Even its correlation with Situational Frequency (SF-2) was only .12. The failure of this variable to be associated with a somewhat similar recognition memory variable can perhaps be explained by the fact that the task was embedded in several other tasks and had insufficient salience to reflect any persistent incidental memory abilities of subjects. The other variable, "Street Names (SA-0)," arose from the use of seven different street names in the scenes seen during the imaginary drive. After the presentation, subjects were given the seven street names and asked to assign the order in which they had been encountered. Again, the scores were z-transformed correlations between judged and true order. On trial 1, performance was very poor, with a mean of .46 (S.D. = .58) indicating a markedly skewed distribution; substantial improvement occurred on trial 2, where the mean was .70 (S.D. = .65). Intertrial reliability was only .23, and the variable had no significant correlations with other variables in the battery and was thus not used in factor analysis. Possibly the trial 2 scores contained enough reliability to have had some significant correlations.

Underwood, Boruch, and Malmi (1978) developed a Background Frequency task to see whether there were useful and reliable individual differences in people's ability to judge the frequency of words in the English language as indexed by Thorndike-Lorge ratings. If such differences existed, it was thought, they would pertain to semantic memory rather than to episodic memory. The task involved having subjects make forced-comparison judgments of the relative frequency of pairs of words. The T-L frequency differences varied across pairs, as well as the base frequency. Mean proportion correct was .646, S.D. = .055 (converted from the authors' error data). The split-half reliability was reported as .28 (not "boosted," apparently; total score reliability would be estimated as .44), disappointingly low. In view of Carroll's (1971) finding that subjects can make fairly accurate subjective judgments of word frequency, and that lexicographers are better at such judgments than non-specialists, this result is somewhat surprising. One might expect frequency-judgment ability to be related to general verbal ability, but it appears that accuracy of frequency judgment was correlated only to the extent of .05 with SAT-V in Underwood et al.'s sample (Table 3, correlation of variables 29 & 32 with sign reflection for reversed scoring of Background Frequency). Background Frequency was not included in the authors' factor analysis. Measurement of this ability could depend critically upon the selection of word-pairs for a forced-choice test. Apparently the pairs in Underwood's test were such as to result in rather low accuracy and little variance; also, there must have been a considerable guessing element since chance guessing would be expected to produce mean scores of .50. Further attempts to measure word frequency judgments could be encouraged, although one cannot be optimistic that this ability would stand apart from general verbal ability, or that it would reflect any special characteristic of "semantic memory." (Cf. results in measuring vocabulary by a lexical-decision, word recognition test; Zimmerman, Broder, Shaughnessy, & Underwood, 1977).

One other task that may be classified here is the Sentence Recognition task studied by Allen, Rose, and Kramer (1978), based on the so-called Bransford and Franks (1971) paradigm in which sentences varying in content and grammatical construction are presented to subjects who are later tested as to exactly which sentences (if any) they recognized as being presented. Scoring emphasized the degree to which subjects were able to recognize parts of sentences on a verbatim or syntactical basis. Day 1-Day 2 reliabilities of various derived scores were very low, ranging from .14 to .31. A total error score appeared, rather weakly but consistently, on factor ALRK-D, interpreted as a Free Recall ability factor. It appears that performance in the Bransford-Franks paradigm is too complex to be clearly sensitive to individual differences in sentence recognition and recall; in any case, it seems dubious that native speakers of a language would differ in their sensitivity to, and recall of, the exact features through which semantic information is communicated.

The results considered in this section suggest that there are indeed reliable individual differences in the degree to which a person notices (and in some way "encodes") events in the immediate past ("immediate," that is, in the sense of the past few minutes or perhaps hours) and can then recognize them as having occurred, and as having occurred, perhaps, with different frequencies. It has proved difficult, however, to capture any such ability, with adequate reliability, in laboratory tasks of limited scope and duration. The results available thus far suggest that there are problems relating to the types of events (numbers, words, sentences, or what not) that should be presented for memory acquisition, and also problems relating to the manner in which recognition should be measured in such a way as to avoid a chance guessing factor and to well reflect the degree to which memory for an event's occurrence has been stored and retained.

Not mentioned here thus far is a task studied by Underwood et al., Recognition of Pairs in a "simultaneous acquisition task," in which the subject is presented with a series of slides representing an imaginary drive through an urban area; during this "drive" the subject knew that he would later be asked to recognize whether certain pairs of words on signs, like exit ramp, had actually occurred. The recognition task had relatively low reliability (.58) but had a fairly substantial loading on factor UNBM-D, Recognition Memory for Events. This sort of task is appealing because it has a more "real world" flavor than many of the other tasks. Thus far, at least in the studies surveyed here, it seems that nobody has experimented with the use of much longer time intervals than the fractional hours that are usually employed in laboratory tasks. It would seem that recognition memory for events in a more distant past would be of more interest and practical consequence in daily affairs. Although there is beginning to be a literature concerned with such memories, individual differences in the retention of such memories have been investigated only sporadically (e.g., Johnson & Klingler, 1976).

ECTs Classified Under Paradigm 5 (Naming/Reading/Association)

This category contains ECTs that require subjects to produce names or other associational or classificatory responses to stimuli. In the view of the long history of the study of such responses in experimental psychology (see Woodworth, 1938, pp. 354-363 for a review of early work), it is surprising that relatively few tasks of this type have been studied from an individual differences standpoint in cognitive psychology, except insofar as these tasks include reading responses, i.e. the "naming" of words. From experimental studies in cognitive psychology, one could tell little about the dimensionality of individual differences in this domain, although information is available from more conventional psychometric and factor-analytic work (see, for example, discussions of various "fluency" factors in the monograph by Ekstrom, French, & Harman, 1979).

The tasks included in this category require not only the apprehension and encoding of stimuli but also the retrieval, from "long-term" memory, of various types of "co-representations." Our classification of these tasks is based on the types of stimuli presented and the types of "co-representations" (coreps) that have to be retrieved. We start with tasks requiring the naming of objects or pictures, continuing with discussion of research with simple "word-naming" or word-reading tasks. (The total skill of reading, as seen in the reading of a paragraph or longer passage, whether silently or orally, is considered outside the boundaries of ECTs; we restrict attention to simple tasks that can be regarded as elementary units of the reading process.) We then take up work with the so-called Stroop task, which involves both reading and naming, and conclude with a consideration of tasks that require the identification and retrieval of abstract names and relationships.

Picture-Naming Tasks

In a laboratory testing situation, it is convenient to present stimuli for object-naming as line drawings, photographs, or similar representations; through pretesting, these need to be made clear and unambiguous as to what is to be named, and for the purpose of measuring individual differences it would be desirable to select stimuli for which there is high agreement among subjects as to the single "best" name. Some investigators have used line drawings but colored slides are preferable for many types of stimulus objects. Some type of voice-key apparatus, with naming time measured from initiation of presentation to response, is generally employed. Adjustment of reaction times for varying voice-key response to different initial phonemes of names is a refinement that is probably unnecessary in ID measurement.

Much of the research on picture naming has been concerned with attributes of picture names (frequency in the language, age-of-acquisition, "uncertainty") that affect naming RTs (Oldfield & Wingfield, 1965; Carroll & White, 1973a, 1973b; Lachman, Shaffer, & Hennrikus, 1974), and these variables must be taken into account in any effort to determine reliable parameters of picture-naming latencies. Although IDs in naming pictures, colors, and forms were observed in early work (Cattell, 1885) and in factor-analytic research (Carroll, 1941; Thurstone & Thurstone, 1941), they have received little attention in recent years. Oldfield and Wingfield (1965, p. 278) found that both subjects (persons) and objects (items named) contributed significantly ($\underline{p} < .001$) to variances of latencies, but focused their attention on the object variance. Over all subjects, their line of regression of mean latency (msec) on the Thorndike-Lorge frequency of the object's name in the English language, expressed as the logarithm of the probability, was approximately as follows (as read from their figure):

$$RT = -402 - 253 \log \underline{p} ,$$

with a correlation of somewhere between -.80 and -.89. Wingfield (1968) obtained very similar results with a new sample. Carroll and White (1973a), however, using a much larger set of pictures, found that a better predictor of latency was the age at which the object's name is typically acquired by subjects. In reporting latencies, they preferred to convert them to reciprocals because of the greater normality of distributions of those values. Over all subjects and words their mean reciprocal was 1.30, S.D. = .25; their results translate to a latency of 770 msec for an object whose name has a frequency of about 17 per million, or is typically learned in the kindergarten

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period (age 4 up to 5). Thorndike-Lorge frequencies correlated with mean reciprocal latencies to the extent of .674, while age-of-acquisition measures correlated with latencies to the extent of .772. Carroll (1976b) studied IDs in reciprocal-transformed latencies averaged over a set of 50 words. From certain data presented by Carroll, one notes that a "fast" responder would have a median latency of about 780 msec for a set of relatively uncommon words (average T-L frequency about 4 per million), while a "slow" responder would have a median latency of about 1390 msec for the same words. Mean reciprocal latencies for subjects were predictable, to the extent of a multiple R of .737, from a set of psychometric variables that included a vocabulary test; however, the only significant predictor was score on a psychometrically designed picture-naming test. Tests such as Hidden Figures, Thing Categories, Controlled Association, Gestalt Completion, and Advanced Vocabulary (most of these from the ETS kit of marker tests) made no significant contribution to the prediction and in fact all had low correlations, ranging from .13 to .35, with experimentally determined latency measurements, while the picture-naming test had a correlation of .69. Carroll concluded that "picture-naming speed is a rather robust parameter of individual differences" (p. 19), and that it should be investigated further.

Carroll's results were for college-age subjects (mean age = 22). A study by Thomas, Fozard, and Waugh (1977), using a picture-naming task, showed that age is significantly correlated with mean latencies. From their graphs, one notes that for pictures whose name-frequencies were comparable to those used by Carroll, mean latency for a group aged 25-35 was about 1090 msec, latencies for groups aged 36-65 centered around 1275, while that for a group aged 65 and older was about 1400. Latencies were approximately a linear function of log word frequency in each of the five age groups studied. These authors also employed a variation of the picture-naming task in which the picture to be named was immediately preceded by presentation of a word that might or might not match the picture; for example, the word DICE might be presented, followed with .5 probability by the picture of a book (a "non-matching" trial). As would be expected, naming latency was greatly shortened in the "matching" trials, but slightly lengthened, over the control condition, in the "non-matching" trials. This effect was similar over age groups. Further:

> A multiple-regression analysis was run to determine the extent to which individual differences in naming latencies on the first trial with a given object could be predicted. Age alone predicted 40.7% of the variance in mean latency. Verbal IQ (Ammons and Ammons, 1962) added another 7.1% to variance accounted for, and the mean time taken to read common English words accounted for an additional 4.2%. Together these three factors produced a highly significant multiple R of .722. Addition of predictors based on other task performances (of particular interest, performance in the matching task) did not add significantly to this predictability. (Thomas, Fozard, & Waugh, 1977, pp. 505-506)

Both Carroll (1976b) and Thomas, Fozard, and Waugh (1977) studied the reduction of latencies that takes place over repeated trials with a set of pictures. The greatest decline occurs from trial 1 to trial 2; according to Thomas et al.'s results, the latencies do not level off for all age groups until about trial 6 or 7. Age differences were still evident even at trial 8. Thomas et al. interpreted the age-related slowing as "probably due to perceptual or motor differences." They also noted that the presentation time needed varied over age: In pilot work, old subjects (56-74 years old) required 115 msec, while young subjects (19-26 years old) required only 84 msec. This last figure is strikingly higher than that reported by Wingfield (1968); see p. 123 above. The difference, however, may have to do with Thomas et al.'s concern with perceptual errors. In any case, in the standard picture-naming task the picture remains visible until it is named. From the standpoint of developing a picture-naming test for operational use, this is the procedure that would be recommended. Also, it would probably be unnecessary to give more than one trial for a given picture.

Word-Naming (Reading) Tasks

Of interest here is how long it takes a subject to read aloud a single word from its initial presentation, and whether there are individual differences in these times that might be related to speed or comprehension in the normal reading situation where eye movements are much more complexly controlled than in an experimental task. It was early discovered (see Woodworth, 1938, pp. 355-356) that naming or reading a printed word is faster than naming the object or attribute (e.g. color) that it might represent. Woodworth remarks that naming a word is intuitively a more "direct" association than picture- or object-naming, and points out that "a word is its own name."

Recent research using a word-naming task has been concerned mainly with processes of word recognition. Butler and Hains (1979) studied individual differences in word-naming latencies and found that high vocabulary subjects were much less affected by word length than low vocabulary subjects. RTs for high vocabulary subjects ranged from about 500 msec for 2-letter words to about 625 for 14-letter words; the corresponding RTs for low vocabulary subjects were about 610 and 980. The RTs were also affected by frequency of the word in the language, but word frequency did not interact with word length or vocabulary scores. It was suggested, therefore, that the subject's vocabulary and the length of the word affect one stage in the word recognition process (early recognition and encoding) while word frequency affects another stage (word retrieval). It was also suggested that high vocabulary subjects use a more holistic word-naming strategy than low vocabulary subjects. These conclusions were further supported with these authors' study of a lexical decision task (see p. 141 above).

Word-naming tasks were used by Frederiksen (1978) in a study of components of reading skills. RTs for naming high and low frequency words, and for naming pseudowords derived from actual English words by changing a single vowel, were used to form several indices of the degree to which subjects process the orthographic information in words. These RTs were also used as criterion measures of reading skill. The results are too complex to be reported here. A highly simplified summary statement would be to the effect that reading skill seems to depend on the automatization of processes of word decoding; these processes are poorly automatized in poor readers, who continue to depend on elementary phonemic decoding processes even for common words.

The word-naming task can be made more complicated by imposing special requirements as to the manner in which it is done, or requiring the subject to perform the task under interfering conditions such as delayed auditory feedback. Such complications were introduced by Lunneborg in two separate studies (1977, 1978). One of the tasks was to require subjects to read or repeat words (as spoken, apparently, by the experimenter), replacing all /r/ sounds with /l/ sounds, and all /l/ sounds with /r/ sounds. (For example, laboratory was to be pronounced as if spelled rabolatoly.) The other task was to require subjects to read nonsense syllables or scrambled English prose under delayed auditory feedback. Both of these tasks had been claimed by Day (1974) to measure "the degree to which one is unable to overcome the conventions or expectations of a native language," or (in terms now employed by Day), to indicate whether one tends to be "language-bound" as opposed to being "language-optional." In the first study (1977), Delay Read Time and R/L Latency were found to be highly correlated, defining a separate factor in a factor analysis of a number of measures. Both also tended to have significant correlations with psychometric measures of verbal ability (vocabulary, grammar). These relations were generally confirmed in the second study (1978). The correlations with verbal ability were, however, quite modest. It would appear that much further development and variations of these tasks would be required to achieve understanding of the extent to which they measure Day's language-bound/language-optional concept.

The Stroop Color-Word Task

Although it is commonly called the "Stroop task" because materials for it were developed and studied intensively by Stroop (1938), it was actually employed much earlier by Peterson, Lanier, and Walker (1925), and probably even earlier than that. Essentially, it requires subjects to name the colors in which words are printed, the words being color names but printed in colors other than those names. For example, the word "green" would be printed in red, with the subject being required to say "red" as the color. Normally the task is presented on cards with multiple lines of color words printed in different colors, and the subject is required to name the colors, reading across each line as rapidly as possible. The time taken to read the colors can then be compared with the time taken to name patches of color arranged similarly, and frequently the final measure is the algebraic difference between the color-word time and the color-naming time, the former nearly always being the larger (longer). In the limit,

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there might be no difference for a person who cannot read the color words, for that person would find the color words no hindrance. (A "Stroop task" printed in Arabic, for example, would present no problem for a person unfamiliar with Arabic writing.) Indeed, it has been shown (Fournier, Mazzarella, Ricciardi, & Fingeret, 1975) that the Stroop task can provide some information about children's word recognition skills. Cognitive psychologists have been much concerned to "explain" the Stroop effect (Jensen & Rohwer, 1966), and there have been discussions and investigation of ways of scoring it (Thurstone, 1953; Jensen, 1965). It is not surprising that it has figured in recent research on individual differences. Versions of the task appear in at least three studies. None of these versions, however, employs measurement of reaction times to stimuli one at a time. One could raise the question of whether greater control of stimuli and more precise measurement of responses could be attained in this manner. (This might suppress the operation of a perceptual speed factor that, as will be mentioned below, may affect results.)

The task used in studies by Hunt, Lunneborg, and Lewis (1975) and Lunneborg (1977, Study 1) was one in which subjects first named the colors of a series of 30 asterisks printed in different colors (the number of colors is not specified, though usually the task employs five easily discriminable and namable colors such as red, green, blue, yellow, and black), then named the colors of 30 color names printed in colors other than the names. Time to complete each of these subtasks was measured in seconds. Results were reported only in a factor analysis of 34 variables. This analysis used both the "asterisk reading time" and a "color name--asterisk reading time" difference variable; the former had a weak loading (.29) on factor HULL-D (interpreted as "ability to hold order information") while the latter loaded on factor HULL-B, interpreted as the ability to access overlearned codes, along with the NI-PI match difference variable and two psychometric tests of clerical speed. Our own interpretation of factor HULL-B is that it strongly resembles the conventional Perceptual Speed factor. The results are problematic, however, because of the use of both the asterisk reading time and the color-asterisk time difference variable in the factor analysis, converting specific variance into common factor variance unnecessarily. It is reasonable to suppose that the Stroop task could involve a perceptual speed element, since the subject has to scan a series of stimuli during performance of the task. Neither of the Stroop task variables loaded on factor HULL-A, which looks like a general intelligence factor. It does not appear that the Stroop task difference score has any useful relation to general mental ability, at least to judge from Hunt et al.'s results. Further, the results obtained by Lunneborg (1977) with the Stroop task are difficult to interpret. In our factor analysis of one of his correlation matrices, a few low correlations between the "Stroop difference" and several other variables produced a separate factor LUNA-A which had loadings on the Stroop difference, digit span, and proportion correct in a choice reaction time task.

The version of the Stroop task used by Rose (1974) involved reading colors of plastic strips with X's printed on them in white, and then reading the colors of similar strips with conflicting color words printed on them in white. Despite this rather deviant format, the main results of the Stroop task were confirmed. Rose gives means and standard deviations of reading times for 72 items; converting these times to times-per-item in msec, we find that on Day 1, subjects took 545 msec per item (S.D. = 90) to name colors, and 807 msec per item (S.D. = 138) to name colors with conflicting printed words. The mean of the (algebraic) differences was 263 (S.D. = 36). In our factor analysis of Rose's correlation matrices, we avoided using the difference scores, analyzing only the color and color-word variables, which were highly correlated. In fact, the correlations increased over the three days of the experiment, from .81 on Day 1 to .88 on Day 3. Reliabilities between days centered closely around .90, except for the reliabilities of the difference scores, which were .68 (Day 1-2) and .72 (Day 2-Day 3). In our factor analyses, the two chief Stroop-task scores defined factors of their own (ROSE-A), but also consistently had moderate to substantial loadings on factor ROSE-D, interpreted as a verbal ability factor partly because of its loading for SAT (Scholastic Aptitude test). From this finding alone, it is impossible to say whether a part of the Stroop variance correlates with some intrinsically intellectual facet of verbal ability, or merely with a speed component of measurements of verbal ability. In any case, it appears that both color-naming speed and color-word naming speed measure the same speed component.

A decision as to whether the difference between color-naming and color-word naming has any status independent of the variables that contribute to it would have to be based on further information than is now available. The situation is analogous to that described for the difference variable derived from Posner-type tasks, the NI-PI variable (see p. 163 above). It would be necessary to show that significant and opposite-signed regression weights could be found in the prediction of some important external criterion variable. We examined Rose's data for possible instances of such a finding, for any other variable. Two possible cases presented themselves: one for the prediction of Rose's RT-Control variable, and one for the prediction of SAT--but only for the results on Day 3 of the experiment, when possibly the characteristics of the Stroop task had settled down to some kind of stability through practice or experience (or, possibly, when the same became true for the RT-Control variable). Although the signs for the color-naming and color-word naming variables were in the "right" direction, both regression weights were significant only in the case of RT-Control. The evidence, therefore, for the utility of computing a "Stroop difference score," opposed to using one or the other of the base scores, is very slim thus far. Even so, the possibility remains that a Stroop difference score would reflect only some speed component of intelligence measurements, rather than any intrinsic ability traits. Nevertheless, the data suggest a potentially profitable area of further research, if the research is carefully performed with an eye to excluding alternative possibilities.

Miscellaneous Other Tasks Under Paradigm 5

It would undoubtedly be possible to cite or imagine a multiplicity of other tasks involving naming, reading, associative, or abstractive responses that might reveal new dimensions of IDs in cognitive processes, but in the studies surveyed here only two additional ones are to be found.

Cory, Rimland, and Bryson's (1977) computerized "Password" task resembles, for example, the Remote Associates test developed by Mednick (Mednick & Mednick, 1967). Initially, two words (e.g., soaring; emblem) are presented as clues to a target word (e.g., eagle) that the subject is to think of and type on a computer terminal; if he is initially unsuccessful, up to three additional clues (e.g., feathers, large, bald) are given. Scores are numbers of correct responses with adjustments for number of clues received. Because of the limitations of Cory et al.'s battery, the tentative result, that the scores correlated with one other test of creative reasoning (Twelve Questions) would need further confirmation and extension.

Whitely's (1977) Relationship Eduction task is an interesting ECT. It was "constructed to measure speed in retrieving information about word relationships from long-term memory." Presented with two words that might function in an analogy item, e.g. deep and cheap, subjects were required to push a button as soon as they "thought of" a relationship between the words, then to write a short sentence describing the relationship. Average time for initial response to the items presented was 6.14 sec, S.D. = 3.83. Scores helped to define a factor (WHIA-A) that Whitely interpreted as memory accessibility, but such a description is probably too unspecific. Experience with this type of task in other connections suggests that it is probably definable in terms of some aspect of "divergent thinking." It would be possible to explore this type of task with greater rigor, by carefully controlling the types of word pairs and the relationships that they could entail. The task has some resemblance to certain component tasks (those of "inference" and "mapping") that occur in R. Sternberg's (1977) treatment of analogical reasoning tasks. More intensive analysis of this type of task is recommended because of its clear relevance to the measurement of cognitive functioning in the perception, production, and retrieval of abstract ideas.

ECTs Classified Under Paradigm 6 (Episodic Memory Read-Out)

Our consideration of tasks classified under Paradigm 6 (Episodic Memory Read-Out) will follow the subclassifications established by the factor-analytic interpretations given in Chapter 3: Memory Span, Free Recall, Paired-Associate Learning, and Verbal Discrimination, along with a number of tasks that seem to reflect episodic memory read-out but that have not received clear assignments to factorial dimensions.

Iconic Memory Tasks

An iconic memory task similar to the one developed by Sperling (1960) was used in only one study surveyed here. In the version employed by Hunt, Lunneborg, and Lewis (1975), 8 letters, arranged in a 2 × 4 array, were exposed for 50 msec in a tachistoscope. Following this, the screen was blank for from 0 to 1 sec, terminated by an auditory cue that directed the subject to recall orally the 4 letters in either the top or the bottom line. There were randomly sequenced delays of 0, 0.15, 0.3, and 1.0 sec. The results figured in these investigators' report in two ways. First, the number of correct recalls at zero delay constituted the first variable selected in a stepwise discriminant analysis to distinguish "high verbals" from "low verbals." While the precise data are not reported, one would assume that high verbals recalled more, and that the discrimination provided by this task was significant. If so, Hunt's hypothesis that high verbals are better able to access letter-name codes would receive support, though not absolute confirmation. Second, two variables from this task were employed in a factor analysis. Both appeared on factor HULL-E; number correct at zero delay had a loading of .62, and a variable obtained by subtracting this from number correct at 0.3 sec delay had an even higher loading, but with opposite sign, -.72. (One could question whether it was proper to include the difference variable in the factor analysis because of the linear dependence problem, but let us assume that that did not affect results seriously.) Neither variable appeared with even a moderate loading on factor HULL-A which we interpret as a general (including verbal) ability factor. The remaining loadings on factor HULL-E were for two intercept variables from the Sternberg task and the Posner Physical Match Time, and we have interpreted this factor as being a more or less simple reaction time factor. There seems, then, to be some conflict, which we cannot interpret or explain, between the factor analysis and the discriminant analysis results. Of possible consequence is the fact that the difference variable had a loading of .36 on factor HULL-B which we interpret as Perceptual Speed. It is conceivable that the discriminant analysis results came about through the correlation of "verbality" with perceptual speed, but that seems unlikely because in that case an information-processing measure of perceptual speed should have had priority in entering the stepwise discriminant analysis. We can only comment that the status of the iconic memory measures needs to be further investigated.

We have classified the iconic memory task under Paradigm 6, "Episodic Memory Read-Out," because it does involve the recall of materials presented to a kind of memory--the "sensory buffer" in this case. As we will see in the discussion (below) of memory span experiments, the types of stimuli and the method of scoring (for items themselves vs. their order) may be critical in assessing results obtained under Paradigm 6. They may, therefore, be critical in assessing results from the iconic memory task.

Memory Span Tasks

Memory span tasks in various forms, but all involving recall of stimuli in order after a single presentation, were included so frequently in the studies surveyed here that a number of interesting questions can be raised about what they measure, and, tentatively and in part, answered. Before discussing them in detail we believe it is useful to draw attention to an important distinction and to what should be a very influential paper by Martin (1978). As Martin notes, the standard digit span task has traditionally been regarded as a measure of memory capacity, i.e., the number of items that can be held in immediate working memory. Her study, however, found that digit span memory, when assessed in the manner recommended by Woodworth and Schlosberg (1954, p. 697), failed to correlate significantly with any of various measures of "primary" and of "secondary" memory applied to free recall tests. Through two experiments, however, she showed that immediate digit span correlated with tests of ability to recall the order of items as distinguished from the identities of the items. From her results, it appears, then, that a digit span test measures not only the ability to recall the identities of the digits presented but also the ability to recall their order. Further, there are apparently two abilities involved here: memory for identities of stimuli, and memory for order of stimuli. A memory span test is inherently a factorially complex measure. The degree to which it measures memory for order, as opposed to memory for stimulus identities, is a function of the stimulus set. If the stimulus set is very limited, as is the case when digits 0 to 9 (or a subset of them) are used, it probably measures order memory more than when letters or words are used, because in the latter case the subject has a greater problem remembering the identities of the stimuli. It is fairly difficult to reduce the effect of stimulus-identity memory; Martin did it by constructing sequences of 3 letter pairs (e.g., BG, FM, RK) with the letters selected always from a fixed 12-letter set. Memory span tasks have also been constructed with even more limited sets, e.g., by using sequences of consonant or vowel sounds drawn from a set of three (Crowder, 1971), but unfortunately no such tests were used in the studies surveyed here. It would be our guess that in a properly designed factor analysis, it would be possible clearly to differentiate memory for order from memory for stimulus identities--i.e. memory capacity for stimulus identities. As matters now stand, it appears that memory span factors arise and are differentiated from free-recall factors mainly because they are more concerned with order memory than with capacity for memory of stimulus identities--measured to a greater extent by free recall tests and thus embodied in free-recall factors.

Moreover, since digit span tests have often been regarded as important or at least useful in measuring general intelligence (see Matarazzo, 1972, pp. 204-206), it becomes critical to inquire as to the respective roles, in such measurement, of memory for order and memory capacity for stimulus identities.

Because of the popularity and theoretical significance of memory span tests using digits, we consider them first. The "standard" digit span test, involving oral or auditory presentation of digit strings of increasing length (e.g., from 4 to 10 or more), at the rate of 1 digit per second, is exemplified in tasks studied by Robertson-Tchabo and Arenberg (1976), Hunt, Lunneborg, and Lewis (1975), Martin (1978), and Berger (1977). Scored in the manner prescribed by Woodworth and Schlosberg (1954), the mean digit span was reported by Martin as 7.41 (S.D. = 1.26) in one experiment, and 7.10 (S.D. = 1.18) in another experiment, using the Oxford University subject pool. These results are apparently typical. Auditory presentation entails successive presentation of the stimuli. Visual presentation was often used, however, with stimuli presented either successively (e.g., Chiang & Atkinson, 1976) or simultaneously, as a "complete" presentation (e.g., Cory, Rimland, & Bryson, 1977, at least for half of their trials). The data do not suggest that auditory presentation produces results any different from visual presentations; Jensen (1971) claimed to find no differences from a correlational standpoint. Nor do we find any suggestion that simultaneous or successive presentation makes any difference in the case of visual stimuli. Rate of presentation, however, seems to make considerable difference in levels of performance: for example, Lansman (1978) found a mean digit span of 6.43 (S.D. = 1.05) with a rate of .75 sec per digit. A .5 sec rate was employed by Cory, Rimland, and Bryson (1977) and by Underwood, Boruch, and Malmi (1978); they do not report results in terms of mean digit span, however. The latter authors report that practically perfect performance was obtained with 6-digit strings, and it appears from their graphs that there were about 5% errors with lengths of 7, 10% with length 8, and about 25% with length 9. An interesting phenomenon was noted by both Chiang and Atkinson (1976) and Underwood et al., namely that when percentage correct is plotted against serial position for different string lengths beyond the base memory span, errors increase with serial position except for the last position in the string, where errors decrease considerably. This result can be interpreted in terms of primacy and recency effects. No investigator, however, attempted to derive separate measures of primacy and recency on the basis of memory span data.

Possibly primacy and recency effects are, however, differentiated somewhat with supraspan lists. With lists of 12 digits, presented 1 digit per second, Martin (1978) found a mean of 48.79% correct (S.D. = 16.09%), and with lists of 15 digits of which only the first 12 had to be reported, Berger (1977) reported 35% of possible correct. Berger's 12-digit list proved to be a measure of what she called an Interference factor, in contrast to the standard length lists, whose scores measured what she called a Registration factor. (See our factor analysis of these results, Appendix A, factors BRGR-A and BRGR-B.)

Berger was also able to measure the interference factor by using two standard-length lists in sequence, in the context of trials in which the subject would not know, until the end of a given list, whether recall of the first list or the second list would be asked for. In a Retroactive Inhibition measure, the subject was given two lists, and then asked to recall the first; mean performance level was 45% correct (out of 88 items possible). If, however, the subject was asked to recall the second list (Proactive Inhibition), the performance level was only 27%. This somewhat counter-intuitive result (poorer memory for an immediately preceding list than for one presumably in more remote memory) seems to indicate that the Proactive Inhibition task measures something quite different from the standard memory span task, and indeed this measure defined a separate factor (BRGR-C) in our factor analysis. Retroactive Inhibition loaded on the Interference factor BRGR-A. The reader may be reminded that measures of field independence/dependence had high loadings on this Interference factor; see p. 106 above.

In all cases cited above where reliability data were reported, the reliabilities were substantial to high. Lansman (1978), for example, reported reliability of .83 for digit spans determined from her visually, computer-presented task; Underwood et al. reported a reliability of .75 for scores (number correct) on their task. Possibly this latter figure was depressed because of the use of a .5-second presentation rate and/or the limited number of string lengths (6 to 9).

Standard memory span tests involving letters of the alphabet as stimuli were employed by both Underwood et al. and Fernandes and Rose (1978); in fact, the tasks were virtually identical except for a very crucial difference that apparently was not noted by Fernandes and Rose: Underwood et al.'s tasks were administered at a .5-sec presentation rate (actually, total duration of a simultaneous presentation was .5 sec per item), whereas Fernandes and Rose used a 1-sec (successive) presentation rate. This difference is likely to account for fairly striking differences between the two studies in percentages correct at different string lengths. For example, while the performance levels in Underwood et al.'s study were superior at a string length of 6 (possibly reflecting differences in the subject samples), Fernandes and Rose obtained clearly superior performances on both "low [phonetic] similarity" and "high similarity" strings of length 9. Also, the Day 1-Day 2 reliabilities for Fernandes and Rose's measures (.86 for low similarity, .82 for high similarity letter strings) were clearly higher than Underwood et al.'s split-half coefficients (.64 and .71 respectively). Fernandes and Rose found significant improvement in performance levels from Day 1 to Day 2, and higher correlations with free recall tasks on Day 2. (From the studies surveyed, no data are available on practice effects for memory span tasks employing digits.) Both Underwood et al. and Fernandes and Rose found that there were decrements in performance levels associated with the use of high similarity (phonetically confusable) letters as compared with low similarity letters, in agreement with results from studies by Conrad (1964).

The memory task employed by Allen, Rose, and Kramer (1978) involved auditory, successive presentation of strings of 5 to 10 letters, with the instruction to recall the last five digits. Since the subjects were not told how long a given string would be, they had to continually "update" their memories as the letters were presented. In analyzing performance, they determined for each subject the intercept and slope of the regression line of proportion correct as a function of string length. As would be expected, there was a considerable performance decrement as string length increased, even though only 5 digits had to be reported in every case. It is possible that this task was a better measure of memory capacity than the standard type of memory span task; the intercepts and slopes were both somewhat correlated with performance on a Mental Addition task, derived from the work of Hitch (1978), that was designed to measure memory capacity, but since Fernandes and Rose used no other memory span task this is only a hypothesis.

Finally, we wish again to mention Martin's (1978) work. In order to measure memory for order using letters rather than digits, she constructed sequences of 3 letter-pairs (e.g., BG, FM, RK) drawing the letters from a fixed set of 12 letters (exactly which letters were employed is not specified, and there is no information given as to their phonetic similarities). These pairs were presented visually and

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sequentially at the rate of .5 sec per pair (thus, a total of 1.5 sec for the presentation); subjects were given 30 seconds to write down their recalls. A strict scoring of the responses, counting only letters recalled in their correct positions in the string, gave a mean performance of 55.90% correct (S.D. = 5.86%), and had a correlation of .63 with performance on a standard digit span test. A lenient scoring, however, which counted number of letters correctly recalled regardless of position, gave a mean performance of 67.12% (S.D. = 5.22%) and correlated insignificantly with digit span performance ($\underline{r}$ = .28, $\underline{n}$ = 16), although it correlated .72 with the strict scoring.

The studies surveyed here contained no examples of memory span tasks using stimuli other than digits and alphabetic letters; we restrict the use of the term memory span to tasks involving a single presentation and requiring recall in the order presented. Tasks involving recall of words, pictures, etc., are to be found described under Free Recall tasks since they did not require recall of order, but merely of identities. We would suppose, however, that any task that requires memory for order after a single presentation would behave correlationally like digit- and letter-span tasks even if the stimuli were other than digits or letters, unless, possibly, the stimuli were unfamiliar or otherwise outside the knowledge-range or immediate competence of the subjects.

Investigators planning to use memory span tasks nevertheless need to give careful consideration of the several variables that appear to affect levels of performance and the correlational behavior of the scores, such as size of stimulus set, nature of stimuli, and possibly rate of presentation. It would be useful to skew the measures more towards measurement of memory for order than has been the case in the past. Measures of the interference factor and of a possible proactive inhibition factor might also be useful in assessing cognitive skills, as well as separate scoring for primacy and recency. None of the studies surveyed here employed Digit Span Backward (i.e., recall in reverse order), which has been claimed to have a higher $\underline{g}$ loading than Digits Forward (Jensen & Figueroa, 1975).

Miscellaneous Single-Presentation Memory Tasks

Hunt and his colleagues studied several variants of the task developed by Peterson and Peterson (1959) and reported interesting differences between subjects with high and low (or at least less high) verbal or quantitative aptitude. In a Susceptibility to Interference task (Hunt, Frost, & Lunneborg, 1973, pp. 106-108), subjects were visually presented in each trial with a CCC trigram (3 consonant letters), followed by a 3-digit number, with instructions to attend to the trigram so that it could be recalled upon a signal after counting backward by 3s from the 3-digit number after varying numbers of seconds. There were four trials at each of the intervals (lags) 3, 6, 9, 12, 15, and 18 seconds. Counting backward constituted a kind of interference for the memory of the initial CCC trigram; thus, the task can be construed as a memory span task with interference. Peterson and Peterson had studied the decrement in memory as a function of lag. Hunt et al. found similar decrements, but reported that subjects with high quantitative aptitude recalled significantly more letters than low quantitative aptitude subjects at most lags. High and low verbal aptitude subjects, however, did not differ significantly. Possibly the verbal groups would have differed if the responses had been scored for correctness of order of the letters constituting the trigrams--a technique of scoring that Hunt employed in other or later experiments. In appraising these results the possibility must be considered that the low quantitative subjects were more handicapped in performing the interfering task, which required a certain amount of quantitative ability, and thus had more interference in remembering the initial stimuli.

High and low verbal ability subjects were reported to differ in their performance on another version of the Peterson and Peterson task (Hunt, Lunneborg, & Lewis, 1975, pp. 204-206). In this version, subjects were shown sequences of 4 alphabetic letters to be recalled after varying lags that were filled by subjects' having to "shadow" a series of digits. Responses were analyzed in terms of transposition and intrusion errors; low verbals made more errors of both types than did high verbals, providing more evidence that the distinction between these two groups was associated with differential memory for order. The scores on this task were among the first to enter in a discriminant function analysis. On the other hand, in the factor analysis of 34 variables in these investigators' study, these variables defined their own factor (factor HULL-C) and did not exhibit significant loadings on factor HULL-A which incorporated most of the verbal aptitude tests. Again we see a somewhat puzzling discrepancy between two analyses of the same data, possibly due to the use, in the factor analysis, of difference variables that overlapped with other variables that generated them.

Another task used in this same study (pp. 202-204) contained some features of a Peterson-Peterson task. One might call it a task calling for the delayed recall of "integrable" words. In the presentation phase, subjects were shown sequences of syllables of various sorts. During the interference phase, they had to read 60 digits aloud. On a signal, they had to spell out as many of the syllables as possible. Some of the syllables presented were parts of common words, e.g. the syllables prob and lem which make up the word problem; such syllables were presented adjacently, but nested among sequences of syllables that did not make up words. High and low verbals were found to be distinctively different in their rates of recall of syllables that made up words. Further tests ruled out the possibility that the results were due to differential word familiarity. According to the investigators, the results are "consistent with the hypothesis that highly overlearned codes are somehow more accessible to high verbal subjects, and that the high verbal subject is more adept at integrating acoustic cues over time" (p. 204). The scores, however, were not entered into the factor analysis done by these authors, and did not figure in the discriminant analysis mentioned earlier. The task deserves to be studied further.

In an earlier pilot experiment (Hunt, Frost, & Lunneborg, 1973, pp. 102-104), still another Peterson-Peterson type of task was employed in conjunction with Wickens' (1970) paradigm for release from proactive inhibition. Again, the basic task is to note certain stimuli for later recall after an interfering task (counting backwards by 3s, in this case). Over three trials of this kind, all the stimuli are selected from a certain category, e.g., vegetables; three words in such a category are presented on each trial. On a fourth trial, however, the three stimulus words are selected from another category, e.g. occupations. When the recalls were scored for number of words recalled on the 4th (PI release) trial, high and low verbals did not differ, but when they were scored correct only if all three words were recalled in the original order, high verbals showed about 80% recall, while low verbals showed about 20% recall. The authors concluded that the difference was due to differential deterioration of order information. This striking result should be tested in a replication of this interesting task, along with other tasks designed to measure memory for order, such as the kinds of memory span tests described earlier. The PI-release task is one that is very easy to administer. (The writer has demonstrated it in his classes.)

Dichotic Listening Memory Tasks

Certain dichotic listening memory tasks employed in the studies surveyed here contain features of memory span tasks and for that reason are considered here. Hunt, Lunneborg, and Lewis (1975, pp. 217-218) used a Dichotic Listening task adapted from Massaro's technique for studying auditory short-term memory. On each trial, subjects were presented sequences of digits or consonant letters dichotically, two digits and two letters to each ear. A signal then cued them as to what they should report--either all stimuli received in a given ear, or all stimuli in a given category (digits or letters). It may be noted that subjects received a total of 8 stimuli on any given trial, a fact that makes this task resemble a memory span task. Further, this size of memory set is at the upper bounds of the normal memory span. The results were used both in high-low verbal ability discriminant function analysis and in the authors' factor analysis. The "category score" (number of stimuli recalled in the "category" condition) was the 4th variable to enter the discriminant analysis, presumably contributing significant variance beyond the first three. In the factor analysis, both the category score and a variable derived from the difference between the category score and the ear score had high loadings on factor HULL-C, along with slope variables from the Sternberg memory-scanning task and two variables from a complex mental manipulation task (the "Sunday-Tuesday task"). The authors suggested that this factor could be interpreted as "the ability to access and scan information in STM, without imposing the additional requirement that the data located be subjected to a transformation" (p. 223). We are not aware that this result has thus far been replicated, suggestive as it is. Of interest also is the fact that the category score had a possibly significant loading (.29) on factor HULL-A, which was represented mainly by various types of psychometric aptitude tests. Further study of this task should explore whether its memory-span features cause it to tap memory for order, as opposed to access of information in short-term memory. Lunneborg (1977) used this same task and found that it correlated with memory span measures.

A Dichotic Listening Task was also studied by Keele, Neill, and de Lemos (1978, p. 5) as a possible measure of ability to switch attention. This was a version of the Gopher and Kahneman (1971) task that was found to predict certain criteria of aviators' flight performance. Pairs of words, either pairs of color names or a color name and a digit, were presented dichotically at two pairs per second. Before the sequence of 3, 4, 5, or 6 pairs started, a tone signaled which ear the subject was to attend to in order to report the digits as they occurred. Thus, there was no memory span feature in this task; it presumably reflected the ability to focus attention to one ear or the other. The task had a high reliability (.92) and correlated substantially with certain other tests designed to measure attentional flexibility. Possibly a task of this sort should be used as a control in exploring the type of dichotic listening test studied by Hunt et al.

Free and Serial Recall Tasks

Structurally, there seems to be little difference between free and serial recall tasks, on the one hand, and memory span tasks, on the other. Yet abilities in memory span tasks tend to have low correlations with abilities in free and serial recall tasks, and we have noted many instances of memory span factors differentiated from free recall factors. What needs to be better understood is what makes for the differences between these two classes of factors. Do they reflect fundamentally different types of memory abilities and processes, or are the differences due mainly to the kinds of task requirements and the strategies different people adopt in meeting those demands?

There are several obvious differences in the types of task requirements. In the memory span task the requirement is to remember the order of a series of stimuli that are presented just once, whereas in the free recall task the requirement is to remember the stimuli in any order. Further, the memory span stimuli are usually either digits or letters, ordinarily very familiar to the subject, whereas the stimuli in free recall tasks are selected from much larger sets, e.g., words of the English language having much more information value, in an information-theory sense, than digits or letters of the alphabet. Also, words and similar classes of stimuli may have more complex associational values than digits or letters. Another difference is that the free recall task usually presents sequences of stimuli considerably beyond the memory span. Frederiksen (1969), for example, studied the acquisition of lists of 60 words each. Finally, free and serial learning tasks often allow substantial time for study and "rehearsing" of stimuli, often over several trials. The rate of presentation is usually slower than in memory span tasks.

If it is asserted that the memory span task measures memory for order while free and serial recall tasks measure something else, one must confront the fact that *serial* recall tasks, at least, seem to put some premium on memory for order. The usual serial recall task, however (at least what goes under that name), involves successive learning cycles such that the subject has the opportunity to acquire the order information in a different way from what may be the case in the memory span task, possibly by noting and acquiring associations between adjacent pairs or groups of stimuli. Indeed, serial learning task scores sometimes load on both free recall and paired-associate factors (Underwood, Boruch, & Malmi, 1978). These complex loadings could arise either from the use of different strategies by different members of a subject sample or from an inherent complexity of the task that is true for all subjects.

Although there is a fairly long history of factor-analytic work in attempting to differentiate memory factors, that work has been thus far generally unsuccessful in clarifying the nature of the factors discovered. We believe that this is because the critical features of memory tasks have been inadequately identified and manipulated in factorial studies. Limiting ourselves to the consideration of the tasks utilized in the studies included in the present survey, we may nevertheless make a number of suggestions about what the critical features may be and how they might be explored in further research. Let us first take up serial recall tasks.

Underwood, Boruch, and Malmi (1978) employed two serial learning tasks; scores on both of them had fairly strong loadings on a paired-associate factor (UNBM-B) and lower, but appreciable loadings on a free-recall factor (UNBM-A), in a five-factor solution of the total set of data. (In certain solutions with up to seven factors, the authors state, the serial learning tasks constituted a separate factor, but this factor was found to be unstable.) The first of these tasks (SL-C) was a "standard" serial learning task that was regarded as a control for the second task. Two 12-word serial lists were presented visually at the rate of 2 sec per word. The words were drawn from a pool consisting of all 5-letter words in the Thorndike-Lorge frequency tables; some of the words were undoubtedly quite unfamiliar to many subjects. After each of three presentations of a list, a test trial occurred in which subjects had 60 sec to write the words they recalled in the correct positions in 12 blanks. Since two of the test trials for a given list were followed by another presentation of the list, subjects had an opportunity to check and reformulate their memories of the words and their positions. According to these authors:

> Correct positioning was required for an item to be called correct. The mean total correct responses per trial were 9.03 (SD = 1.98) and 9.27 (SD = 2.06) for the two lists in order, with the reliability being .71. (p. 402)

In the other task (Serial Learning: Positioning, SL-M), stimuli were drawn from the same pool as before and the procedures were identical, except that the recall requirement was removed by permitting the subjects to see the stimulus words during the test trials. All the subjects had to do was remember the correct positions of the words, and report those positions by writing the words in the appropriate blanks. Results were as follows:

> The mean numbers of correct responses per trial were 9.67 (SD = 2.16) and 10.17 (SD = 1.84) for the two lists, and the reliability was .68. Performance on this task was only marginally better than performance on SL-C. (p. 403)

The second task had a slightly higher loading (.50) on factor UNBM-B, the "paired-associate" factor, than that of the control task (.43), indicating, possibly, that the learning of the positions of the words was done by noting particular positions and adjacencies in a paired-associate fashion. It is of interest that the positioning task had a smaller loading (.11) on factor UNBM-C, the memory span factor, than did the control task (.24), possibly indicating that the memory for order in the control task was done more in a memory-span mode (remembering particular sequences of words). It is a little surprising that the performance on the positioning task was not greatly superior to that on the control task, but perhaps there was a ceiling effect operating, since even on the control task where the subjects had to remember the words, the percentages correct were more than 75%; those on the positioning task were about 81% and 87% for the two lists. Possibly the contrast could have been brought out by making the lists somewhat longer than 12 words. Also, separate analysis by trial might have been instructive; one would think there might be a greater contrast between the tasks on the first trial.

Results for three serial learning tasks were analyzed in a report by Malmi, Underwood, and Carroll (1979). In each task, 2 serial lists were each presented by lantern-slides for 2 study-test trials, with 90 seconds allowed for the test phase. The lists varied only in the nature of stimuli to be learned and recalled in order. In task SL1, each list consisted of 24 words, each word being shown for 4 sec. In task SL3, the stimuli were 8 triplets of words, each triplet being shown for 12 sec; subjects were instructed that the triplets themselves had to be recalled in the order shown, but that the words within each triplet need not be reported in the order shown. In task SLS, the stimuli were 12 3-word sentences like "Jogger lost medal," to be recalled in the order shown on the study trials. In the factor analysis of data from these and other memory tasks, the serial learning tasks loaded substantially only on the free-recall factor MAUC-A; loadings on a paired-associate factor MAUC-B were negligible. These two factors, however, were highly correlated (.85). Although the authors were puzzled about the apparent discrepancy between these and the earlier results, it may now be suggested that the difference may have been due to the greater difficulty of the learning tasks in this study, which had from 24 to 36 words to be noted in each list, or from 8 to 24 separate items whose order had to be noted. In fact, the size of the factor loadings is negatively correlated with the number of things to be ordered: .45 (task SL3, 8 things ordered), .39 (task SLS, 12 things ordered), .31 (task SL1, 24 things ordered). Thus, the more things whose order had to be noted, the lower the factor loading, and the less the task measured the basic free-recall ability measured by other tasks that did not require order. In a repetition of this study it would be useful to include several tasks, including memory span tasks, that would be designed to measure memory for order and not free recall. One of the tasks could be similar to the task SL-M used in the earlier study, in which subjects only had to note position.

We can mention only one other task that has some of the characteristics of serial learning that might be further investigated. In Whitely's (1977, p. 468) Short-Term Retention task, subjects viewed an analogy stem, e.g. "Deep: Cheap :: Shallow: _____", and were asked to study it so that they could remember it. Up to 5 sec were allowed for study, but study times were recorded, as well as any errors (presumably, including errors of order) in the recalls that took place after study. Average study time was 3.49 sec (S.D. = 1.66) for this type of task, and this variable had a loading of .67 on factor WHIA-A interpreted as "memory accessibility." This finding prompts the suggestion that studies of serial learning should investigate the one-trial study times required by subjects to remember without error a simple sequence of stimuli like that exemplified here, and particularly, to remember the sequence of stimuli without necessarily remembering the stimuli themselves. Common experience and some evidence suggest that individuals differ widely in the study times they would require to perform without error. Of course, the nature and number of stimuli involved would be taken into account in any such research.

Turning now to pure free recall tasks, we find the most informative study to be that by Underwood, Boruch, and Malmi (1978, pp. 399-401) who factor-analyzed six variables derived from tasks clearly falling in the free-recall paradigm. The tasks are listed here in the order of their factor loadings on factor UNBM-A in its orthogonalized form (UNBM-a); certain other data are given:

			Loadings on:		Other Loadings	Reliability	% Correct List 1
			a	g_m			
3	FR-CO	Free recall: Concrete	.515	.611	.211 (d)	.70	66.8
2	FR-S	Free recall: Spacing	.492	.640	.270 (e)	.68	42.7
1	FR-C	Free recall: Control	.477	.625	.144 (c)	.68	42.9
4	FR-AB	Free recall: Abstract	.370	.590	.387 (d)	.60	46.5
5	FR-II	Free recall: Interitem Associations	.362	.621	.296 (d)	.69	78.0
6	FR-CA	Free recall: Conceptual Associations	.331	.568	.270 (d)	.72	69.2

In all cases, the variables represent number of items recalled, regardless of order, from presentation of lists of words presented for a single study trial. For FR-C, the words were drawn from the same pool as that described for these authors' serial learning tasks, but for the other tasks they were subject to various types of restrictions, the details being as follows:

FR-CO Free Recall: Concrete: Two 24-item lists of words with high concreteness, shown at the rate of 4 sec per word.

FR-S Free Recall: Spacing: Two lists, each having a total of 56 words, but 32 different words, shown at a rate of 4 sec per word; 24 of the words were presented twice, 12 adjacently ("massed"), and 12 spaced from 3 to 20 words apart. There was no evidence of different processes associated with the massed and spaced words, though there was superior recall for the spaced words.

FR-C Free Recall: Control: Four 24-item lists of 5-letter words drawn from the Thorndike-Lorge pool and placed randomly, presented at the rate of 4 sec per word.

FR-AB Free Recall: Abstract: Two 24-item lists of words with high abstractness, shown at the rate of 4 sec per word.

FR-II Free Recall: Interitem Associations: Two 24-item lists of words, each made up of 12 pairs of associated words like doctor-nurse and shallow-deep, presented at the rate of 4 sec per word. (A clustering score, CL-II, was computed but not used in the factor analysis because it had few significant corelations with other variables.)

FR-CA Free Recall: Conceptual Associations: Two 24-item lists of words, each made up of three instances of each of eight categories (e.g., table, chair, bed as instances of furniture) placed randomly but not adjacently by categories, shown at the rate of 4 sec per word. (A clustering score was computed but not used in the factor analysis; it did, however, correlate .71 with CL-II, and .37 with FR-CA.)

All the tasks involve the ability to notice, encode, and retrieve multiple items as single entities dissociated from the positions in which they appeared in lists; in fact, over the 2 to 4 times a given list was presented, the items would generally appear in different positions because they were placed randomly (except for certain restrictions noted above). It is this ability that we believe is essentially reflected in the loading of the tasks on factor UNBM-a. Certain characteristics of the items, however, make for variations in the difficulties of acquiring them. Examining the percentages correct on the first trial of a given list (which would give a better estimate of difficulty than the percentages over all lists for a task), we find that as compared to the control task, interitem associations, conceptual associations, concreteness, and then abstractness assist in recall, in that order of degree. This order, however, does not explain the order of factor loadings on UNBM-a. It is, however, somewhat associated with the extent to which the tasks load on factor UNBM-d, which we have interpreted roughly as "memory for events." Possibly, therefore, people who can use a strategy of noticing certain kinds of associations or characteristics of the words as "events" will have greater success in free recall tasks. Such noticing is conceived to constitute a process over and above that of simply "registering" or encoding the item for later recall.

The small but possibly significant loading of the Spacing task on factor UNBM-e, the "verbal discrimination," may indicate that high ability on this factor facilitates using item repetitions in encoding them. The small (but possibly meaningful!) loading of the Control task on factor UNBM-c, the memory-span factor, may indicate that some people tend to fall back on memory span abilities in performing a free recall task when the items are simply a random set.

One other free recall task studied by these investigators was one that was embedded in a "simultaneous learning" procedure that presented slides depicting scenes that would be seen during an imaginary drive through an urban area. (This setting has been mentioned earlier, p. 185.) The free recall task, about which subjects were explicitly informed in advance, was that of observing and remembering for later recall the names of companies, e.g. "Eagle Chemicals," that would be encountered. Each such "company name," consisting always of two words, occurred twice during the presentation, along with other things to be observed and remembered. There were two trials on the total task, and there were 30 company names. Recall performance was very poor on both trials, but improved markedly from the first to the second trial. Means were, respectively, 1.86 (S.D. = 1.59) and 6.91 (S.D. = 3.41), and the reliability of the scores was .64. The scores had a very low communality (.217) in the factor analysis, indicating that there was much variance unaccounted for in the common factor space. It is interesting that despite low communality and relatively low reliability the scores nevertheless had their only significant loading (.262) on the free-recall factor UNBM-A.

In a further study, Malmi, Underwood, and Carroll (1979) reported on a factor analysis of three free recall tasks that were included in a battery designed to explore relationships between free recall, serial recall, and paired-associate tasks. Paradigms and their typical procedures were crossed with the types of items typically used in the paradigms. FR1 was a "standard" free recall task in which two lists, each of 24 words drawn from the Thorndike-Lorge pool of 5-letter words, were presented for two study-test trials at the rate of 4 sec per word in the study phases, with 90 seconds allowed for written recall. In FR3, the lists consisted of 8 triplets of words drawn from the same pool as before (e.g., fairy gourd udder). Each triplet was shown for 12 sec in the study phase. Again, 90 seconds were allowed for written recall. The triplets could be recalled in any order, but the three words within a triplet had to be written together (though in any order). In task FRS, each of two lists consisted of 12 3-word sentences like "Girl drove donkey", each shown for 6 sec, one after the other, on the study trials. During the 90-sec recall phase, the sentences could be written in any order, but the words of each sentence had to be written together. The study sought to determine whether the factorial structure would depend more on the overall procedure (free recall, serial recall, or paired associate) or more on the types of items in the lists (separate words, groups of words, or sentences). The finding was that the structure depended almost exclusively on paradigm and procedure. All three free recall tasks appeared on a factor MAUC-A that also had appreciable loadings on serial recall tasks. In contrast, factor MAUC-B had loadings on all the paired-associate tasks. The loadings of the free-recall tasks on factor MAUC-A could be said to correlate positively with the number of words within the items to be recalled, and negatively with the number of separate items to be recalled, as may be seen here:

Task	Percent Correct	No. of Words in Each Item	No. of Items To Be Recalled	Factor Loading on MAUC-A	Reliability
FR1	56.4	1	24	.34	.75
FR3	56.4	3	8	.48	.56
FRS	64.9	3	12	.49	.65

Of course, these correlations may be only chance, but the trends suggest that in further research, number of words per item and total number of items to be recalled could be manipulated in order to see which of these variables governs the size of the factor loadings. The factor loadings are not correlated with the proportion correct, and if anything, they are negatively correlated with task reliabilities, so that increased reliabilities would be expected to enhance the effects noted above.

Immediate free recall tasks generally similar to those used by Underwood and his colleagues have been studied by other investigators, and when a sufficient number of them are analyzed in a factorial battery they tend to appear on free recall factors; the results are covered in Chapter 3 (pp. 108-109).

Little attempt was made, in the studies surveyed here, to analyze free recall performance more intensively and deeply by looking at detailed aspects of performance. However, Robertson-Tchabo and Arenberg (1976) scored an immediate free recall performance in terms of (a) recall of words in the last five positions of a 12-word list, as a measure of "primary" memory, and (b) recall for the words in the first seven positions, as a measure of "secondary" memory--memory not in immediate attention. These scores proved to have loadings on different, practically uncorrelated factors, factor ROBA-E ("Primary memory") and ROBA-D ("Secondary memory"). It is noteworthy that a delayed free recall test, in which subjects were asked, after an interpolated task, to recall the words they had been given in the immediate recall test, had its expected loading on the secondary memory factor. Thus, ability to retain and recall material after an interval of time and after interpolated activities is not the same as the ability to recall the material immediately. Many would argue that "secondary memory" is more important than "primary memory" in daily life and occupational settings. Though Underwood et al. could be said to be dealing with "episodic" memory in the sense of memory for any events in the immediate or the more remote past, what they were really dealing with, for the most part, was a combination of primary and secondary memory, since they used only total scores on their free recall tasks. Some caution should be observed in accepting the significant correlation (.57) that Martin (1978) obtained between immediate and delayed free recall because the delayed recall variance may have been associated only with the "primacy" or "secondary memory" aspects of an immediate free recall task, and not with the "recency" or "primary" memory aspects of such tasks.

The scoring procedure employed by Robertson-Tchabo and Arenberg (1976), though it may have been convenient for their purposes, may have been only a gross approximation to the information that could be derived from detailed analysis of free recall responses. Frederiksen (1969), using principal component analysis, found that at least five dimensions were needed to describe the learning performances of 120 subjects acquiring a 60-word list over 18 trials under three different conditions, including free recall. A similar procedure was employed by Leicht (1972), but it remains to be shown how such procedures can yield theoretically meaningful information about learning and memory. Frederiksen found only slim evidence that parameters of learning curves obtained in this way could be predicted from patterns of abilities, and he concluded that "the amount of information about human learning obtainable from learning curves may be limited, and that precise prediction of learning performance curves may not be the most important function of a learning theory" (1969, p. 68). Despite this rather pessimistic conclusion, we believe that further efforts should be made to analyze different aspects of learning and memory performance. Frederiksen's findings about people's observations of their own strategies deserve further attention.

A type of analysis that has appealed to many researchers in verbal learning, and to some in the area of IDs, is the computation of indexes of "clustering," that is, indexes of the extent to which subjects tend to group items by logical or semantic categories when they are free to recall items in any order. This is done on the assumption that list learning under free recall instructions may be facilitated, in some people, by the use of associations or categorical relationships between items. Hunt, Frost, and Lunneborg (1973) found, however, that under some conditions (when words from different categories are mixed in a list), "high verbals" rely less on clustering than "low verbals," possibly because they have greater ability to encode and otherwise "register" the raw material of a list and do not need to use clustering strategies. Clustering measures have been applied to free recall performances also by Lunneborg (1977), Allen, Rose, and Kramer (1978), and Underwood, Boruch, and Malmi (1979). Lunneborg found a Clustering Base variable (amount of clustering upon the second presentation of a blocked list) significantly negatively correlated with each of a series of psychometric aptitude tests, supporting Hunt et al.'s finding. Allen et al., however, found their clustering measures, based on a certain sentence recall task, to have very low reliabilities, and the factor analytic results with this measure are virtually uninterpretable. As we have noted, Underwood et al. computed clustering measures on two of their free recall tasks but although these measures intercorrelated to the extent of .71, they failed to correlate significantly with any other variables--even with any of several measures of verbal ability. All these results present a rather puzzling spectrum. Even though there appear to be consistent tendencies among some people to use clustering strategies in free recall, these tendencies are not reliably related to ability, nor are they reliably correlated even with successful performance on free recall tasks. Generally, the evidence impels one to feel that further research with clustering measures will be unprofitable in differential psychology, unless, possibly, clustering is seen as one of many different strategies in learning and memory performances.

Nearly all the work surveyed here on free recall (or for that matter, any kind of recall) has involved verbal or symbolic materials. A few tasks included in these studies have involved other kinds of information, such as spatial information. Cory, Rimland, and Bryson (1977) employed a computer-administered Memory for Patterns test that required subjects to reproduce patterns that were shown by sequentially blinking dots on a grid. Factorially, scores on this test appeared on factor CORB-H which was otherwise defined only by a test called Recognizing Objects (see p. 125). Possibly its apparent spatial component was not captured because the battery included no spatial ability marker tests. A memory task developed by Salthouse (1975) offers possibilities for detailed examination of memory for verbal as opposed to spatial information. Kail and Siegel (1977) used this task to study sex differences in verbal vs. spatial memory. In a 7-sec presentation, subjects are shown a 4 × 4 matrix with 3 to 7 letters placed in some of its cells. Prior to the presentation, subjects can be asked to remember (a) just the letters, (b) just the positions in which letters occur, or (c) both the letters and the positions. The advantage of this task is that memory for verbal and spatial information can be compared directly.

Paired-Associate Tasks

Paired-associate tasks are characterized by the fact that the subject is required not only to encode, for later recall, one or more stimuli (as in the free recall situation) but also to recall them contingently and differentially on one or more cues. That is, the associations between the cue-stimuli and the response-stimuli must be learned. Customarily, the cue-stimuli are called simply "stimuli" and the response-stimuli are called simply "responses," because in the test phase of the task the cues are given as stimuli for the subject's response. It is possibly this double requirement that makes paired-associate tasks a better measure of a general factor of memory, if we accept what was found in the second-order analysis made of the data of Underwood, Boruch, and Malmi (1977; see p. 111 above and Appendix A in this report).

The data on paired-associate tasks that were included in some of the studies surveyed here give certain indications concerning what makes a paired-associate task a good measure of the Paired-Associate factor of memory ability. Underwood et al. included four paired-associate tasks in their study. Each task involved two lists consisting of 12 paired stimuli; the stimuli were in all cases words. (Conventional tests of the Associative Memory factor use pairings of words and other kinds of stimuli--pictures, numbers, etc.) The "study-test" method was used; that is, the stimulus pairs were successively exposed to the subject, and after all pairs had been exposed, there was a test phase during which the cue-stimuli alone were presented, and the subject attempted to write the required response. (In one of the tasks, Matching, both stimulus and response terms were given, the subject being required only to indicate how they were to be matched. Thus, the recall aspect of the task, as far as the response terms were concerned, was eliminated.) In all cases, there were three such study-test trials, and therefore the subject had considerable opportunity to learn the pairings through multiple exposures, possibly profiting from feedback. It is possible that this learning opportunity is one feature of these paired-associate tasks that differentiated them, factorially, from the free recall tasks studied by Underwood et al., which had only a single study trial.

Relevant data for the four tasks, listed in the order of their loadings on the orthogonalized factor UNBM-b, are as follows:

	Loadings on:		Other Loadings	Relia-bility	% Correct,	
	b	g_m			List 1	List 2
11 PA-II Paired-Associates: Crossed Associates	.499	.755	--	.77	87.9	89.5
12 PA-CA Paired-Associates: Conceptual Interference (Paired Categories)	.427	.697	.142 (d)	.67	85.4	83.3
10 PA-M Paired-Associates: Matching	.404	.687	--	.80	90.2	90.4
9 PA-C Paired-Associates: Control	.376	.694	.142 (a)	.75	78.1	88.9

All the tasks were quite easy. This is probably due to the fact that the lists contained only 12 pairs each, and to the use of a 4 sec/pair (15 pairs/min) rate of presentation. (The investigators found it necessary to increase the presentation rate to 2 sec/pair [30 pairs/min] in the case of the Matching task.) In future work, reliabilities, difficulty, and possibly factor loadings could be increased by lengthening the tasks and using higher presentation rates. The task having the highest loading on factor UNBM-b was Crossed Associates, in which pairs of associated words (e.g., day-night, hammer-nail) were "inappropriately" paired (e.g., day-nail). Previous research had shown that such "crossing" of associates seemed to produce interference. The investigators concluded that there was little evidence of interference in this study, since the mean percentage correct was even higher than that in the control task. Nevertheless, the interference effect may have shown up in the factor loadings, since this task had a high correlation (.71) with the Conceptual Interference task, in which the paired words were "inappropriately" paired instances of categories (e.g., aunt-plum, uncle-peach). If the critical element in paired-associate learning is the learning of the pairings, the Matching task, previously described, ought to have been the best measure of the factor, but it was not, having a loading on UNBM-a of .404, despite a reliability of .80. Possibly the task was not difficult enough. The net effect of the data does not exclude the possibility that further research, with tasks of appropriate difficulty, would show the critical element to be the learning of pairings. In fact, the further study reported by Malmi, Underwood, and Carroll (1979) would seem to support this idea. In that study, the highest loadings on the paired-associate factor MAUC-B were for tasks in which, in effect, the subject had to learn a multiplicity of pairings for each stimulus word. For example, in task PA-4St, which had the highest loading, the pairing of 6 different response words with each of 4 different stimulus words had to be learned. The mean percentage correct was only 46.7.

Both Underwood, Boruch, and Malmi (1978) and Fernandes and Rose (1978) used a task, List Differentiation, which might logically be classified as a paired-associate task. In both cases, however, factor analyses showed it to measure a free-recall factor, though somewhat weakly. Our "logical" classification of it as a paired-associate task comes from the fact that it requires the subject to note and recall which of three successive lists a particular word appeared on, i.e. the pairing or association between list number and word. Possibly this test measured free-recall because subjects dealt with it by a free-recall strategy, i.e., learning the lists as free-recall lists and then, upon testing, reporting which list the word had appeared in. Subjects with better free-recall ability would presumably be in a better position to report list numbers accurately. If list-numbers had been more explicitly paired with words the task might have measured paired-associate ability.

Another task used by both Underwood et al. (1978) and Fernandes and Rose (1978) that could be classified as falling in the paired-associate category was named Interference Susceptibility. In this task, subjects are presented with lists of word-number pairs. Within a set of lists, the lists contained the same words but they were paired with the numbers in different combinations and presented in different orders over trials. In theory, the subject's ability to resist the strong proactive inhibition would be tested. Underwood et al. reported a reliability of .81 for this task, but it was not used in their factor analysis because preliminary work did not produce clear patterns of factor loadings for it. Inconsistent results were also found in our factor analyses of data given by Fernandes and Rose, although the task tended to be associated with Factor FERO-B, a composite factor containing Memory Span, Running Recognition, and Situational Frequency. Because of the high reliability of the task, it should be further investigated, but with sufficient marker variables and comparable but slightly different measures of interference susceptibility to define a separate factor if one exists. Fernandes and Rose reported that subjects tried out different strategies in dealing with the task; possibly the task could be redesigned so as to accentuate each of several possible strategies.

One would expect a strong paired-associate memory component in a task, variously called Verbal Problem Solving (Lunneborg, 1977, p. 320) and Fact Retrieval (Lunneborg, 1978, p. 157), in which subjects have to learn to criterion a list of statements linking such things as names and occupations (e.g. "Smith is a carpenter"), names and locations, locations and settings, and settings and activities. A week later, after a recall test of mastery of these "facts," a series of true-false questions was given, for example, "Can the carpenter see the fountain?" Questions were such as to require the retrieval of 1, 2, 3, or 4 facts. Response times were taken and the variables used were the slope and intercept of the line of regression of correct response time on number of facts required to answer the question. Inasmuch as the facts were supposed to have been well mastered, the paired associate component would not be important in the slope and intercept measures; in Lunneborg's work, the slope and intercept variables appeared on two different factors which are difficult to interpret. The paired associate component would, however, presumably operate in the initial learning phase of the test and any immediate or delayed testing. It is possibly of interest that a test very much like Lunneborg's task--perhaps modeled on it--is apparently in use in the Federal Republic of Germany as a part of a medical aptitude test. Sample items are given in Der Spiegel of April 2, 1979, pp. 231ff. A translation of some materials from this test ("Fact Learning") is as follows:

Characterizations: (study materials)
  Huber: Age 10, elementary school, only child, measles.
  Störri: Age 60, widow, lives in Altenheim, broken bone.
  Hürrlimann: Age 40, salesman, auto accident, in shock.
  Bauer: Age 25, merchant, football player, broken collarbone.
  Müller: Age 75, authoress, in intensive care, cancer.
Questions: (to be answered from memory only, after taking several other tests)
  The widow: (A) has cancer; (B) is aged 75; (C) has a broken collar bone; (D) lives in Altenheim; (E) is named Huber.
  In intensive care is: (A) the patient with the auto accident; (B) the authoress; (C) Mrs. Störri; (D) the patient in shock; (E) the only child.
  Etc.

We would suppose that this test would measure paired-associate memory as well as whatever reasoning processes might be required to make the correct inferences from the information in the "characterizations." Note also that the questions are given only after the administration of several other tests; it would thus be a test of delayed paired-associate memory.

Evidence is mixed as to whether paired-associate learning is related to abilities outside the domain of memory. As noted, paired-associate variables were only slightly related to verbal ability variables in the study by Underwood, Boruch, and Malmi (1979). Hunt, Frost, and Lunneborg (1973, pp. 108-109) report significant correlations between verbal ability and errors to criterion for acquisition of number-word pairs, the word-responses being either nouns ($\underline{r} = -.51$), verbs ($\underline{r} = -.45$), or adjectives ($\underline{r} = -.29$) in three corresponding groups of subjects. Correlations between verbal ability and number of words recalled after 5 weeks were .30, .15, and .21, respectively. The significance of these results may be questioned, however, the Ns being actually only 20. (This experiment has been reported by Nelson, Fehling, & Moore-Glascock, 1979, but the authors give no information on, or further analysis of, the verbal ability correlations, being concerned only with certain problems about savings in relearning.) The psychological literature contains much more information about correlations of paired-associate learning and other abilities but it will not be reviewed at this time.

The Continuous Paired-Associate Memory Task

The continuous paired-associate memory task developed by Atkinson and Shiffrin (1968) to explore a mathematical theory of learning and memory has been used by several investigators to study individual differences. In this task, the subject is initially presented with a set of paired stimuli (e.g., word-number pairs) and asked to learn the responses. As the pairs are tested, however, new response terms are assigned. The subject has to revise his memory so that the new response can be given when its stimulus reoccurs, which can occur after a varying number of intervening stimuli; the number of intervening stimuli is called the "lag." Probability of correct performance can be plotted as a function of lag, and one can compute estimates of the four parameters that, according to Atkinson and Shiffrin's formulation, determine the shape of this curve. However, it should be pointed out that very large numbers of trials are required to permit reliable estimates of these parameters for individual subjects. Most investigators have resigned themselves to evaluating performance of individual subjects by noting the number correct in a series of trials. Hunt, Frost, and Lunneborg (1973, pp. 96-99), however, estimated these parameters and reported that high and low quantitative aptitude students differed significantly on some of them; high quantitative students had higher mean values on the parameter α, indicating a higher probability of placing an item into short-term memory, and lower mean values on τ, indicating a lower rate of loss of retrievable information from intermediate term memory. (Hunt & Lansman, 1975, p. 89, fn. 1, have revised the significance levels originally reported for these data; the correct significance levels are .01 and .001, respectively.) No significant differences between high and low verbal aptitude students on any of the parameters were reported.

These results have not yet been replicated because other investigators have not attempted to derive individual parameters. Rose (1974) used a version of the task and obtained total number correct as an estimate of the parameter θ. The reliability of this variable was .51 for Day 1-Day 2 and .72 for Day 2-Day 3. In our factor analysis of his data, this variable appeared, though very weakly, on factor ROSE-D, interpreted as a measure of general verbal aptitude. Lansman (1978) used the task as the primary activity in a dual-task setting and obtained proportion correct under two conditions (easy recall, hard recall); these two variables defined factor LANA-B in our factor analysis of her data, but had no significant correlations with the verbal composite of the University of Washington Pre-College test. Love (1977) developed a version of the task that had considerable realism, being cast into the form of a computer programming task in which variables were assigned different values as the program progressed; the subject had to keep track of, and remember, these changing assignments. Love obtained correlations between a number correct score on this task and several other tasks (e.g., .54 with Guilford's Perceptual Speed test); the Ns are too small, however, to make the data amenable to further analysis or interpretation.

Because of the theoretical interpretations that can be made for the parameters derivable from the continuous paired-associates task, it remains a challenge for courageous and very ambitious investigators who might be able to obtain the required data on large numbers of subjects and correlate the task parameters with other measures of cognitive performance.

Verbal Discrimination Tasks

Underwood, Boruch, and Malmi (1978) studied a series of tasks under the rubric of what has been called "verbal discrimination." In their words, these are tasks "which emphasize the discrimination among memories and . . . in which associative retrieval processes may play only a minor role" (p. 402). From the subject's point of view, the task consists essentially of attending to a series of stimulus pairs in which one member of each pair has been underlined or otherwise marked as the "correct" member, and later being tested, with unmarked pairs, for ability to indicate which member of each pair is "correct." Underwood et al. used three varieties of this task: a Control task (VD-C) in which the stimuli were formed by random pairing of relatively rare two-syllable words from the Thorndike-Lorge count; an Affective Cuing task (VD-A) in which the marked words of the pairs differed systematically from the unmarked words on either the evaluative or the potency dimension of Osgood's semantic differential scales; and a Double Functions (VD-DF) task in which a given word could be the "correct" member of one pair and the "incorrect" member of another pair. All lists consisted of 24 pairs and were given for a single study and test trial; presentation was at the rate of 2 sec per pair on the study trial and 4 sec per pair on test. The first two of these tasks are quite easy; we compute the mean percentages correct as 87.4 and 85.5, respectively, for the sample studied by these researchers; reliabilities are given as .80 and .67. Interestingly, and in contrast to results that had been previously obtained, the affective cuing did not enhance performance on the second of these tests as compared with the first, control task. In an incidental learning setting, one might not expect subjects to notice the cuing. The third task was quite difficult, with a mean percentage correct of 42.8 and a reliability of .66. The first two of these tasks correlated .55 with each other and defined a separate factor in a factor analysis; neither had significant correlations with verbal or quantitative aptitude measures. The third task did not correlate significantly with the first two or, in general, with other variables in the study, and was not used in the factor analysis. Whatever ability was measured by the third task, therefore, was not adequately represented in the battery and does not lend itself to ready interpretation. Even the ability represented in the first two tasks is not easily interpreted because it appeared in only two quite similar tasks. Of possible significance is the fact that scores on both tasks were correlated .39 and .34, respectively, with the Interference Susceptibility task mentioned earlier (p. 220). Also, the Verbal Discrimination factor (UNBM-E) had significant loadings on several tasks (Free-Recall, Spacing, and List Discrimination) that involved the possible "tagging" of items in terms of repetition or their appearance in a particular list. Verbal discrimination ability thus may be interpreted as a rather specific ability (or strategy) to notice and keep track of particular attributes or codes of items when they are assigned such attributes or when such assignments can arise from the way the items are involved in the task. This interpretation could be checked in further factor-analytic work. It should also be mentioned that VD-C and VD-A had small but possibly meaningful loadings on factor UNBM-D which we have interpreted as Memory for Events.

Verbal discrimination tasks, as such, were not used in any of the other studies surveyed here.

ECTs Classified Under Paradigm 7 (Analogical Reasoning)

Using what he calls componential analysis, R. Sternberg (1977) has made detailed studies of several forms of analogical reasoning tasks exemplified in typical tests of intelligence and scholastic ability, in an effort to provide a perspective on the nature of intelligence. Componential analysis is a special method of task analysis and will be described below because of its possible applications to cognitive tasks other than analogical reasoning.

The analogical reasoning task, discussed in Chapter 2 and depicted in Figures 3 and 6, is probably too familiar to the reader to need description here. In Sternberg's adaptation, several important and useful changes have been made, including at least the following:

1. The task may be presented in two stages, a "cue" phase and a "solution" phase. If an analogy is formalized as A : B :: C : D (or D', where D' is an incorrect or

otherwise inappropriate solution for the analogy), the break between cue and solution phases may occur between A and B, between B and C, or between C and D (or D'), so that a subject can have 1, 2, or 3 cues before being presented with the stimulus or stimuli for the solution phase. The zero-cue condition occurs when all four terms of the analogy are presented at once. The four cue conditions, then, can be depicted as follows:

Solution phase

0 cues: A : B :: C : D (D')
1 cue: A : B :: C : D (D')
2 cues: A : B :: C : D (D')
3 cues: A : B :: C : D (D')

Cue phase

2. The testing of performance can be done in two ways. One method, used in the Verbal Analogy Experiment (mentioned below), is to have the subject evaluate the appropriateness ("truth" or "falsity") of the final term, that may be either an appropriate completion (D) or one that is somehow less appropriate or actually incorrect (D'). The other method, used in the People Piece task described below, is to have the subject make a forced choice between two alternatives D and D' that differ in appropriateness. (Sternberg's procedure, incidentally, did not differentiate between decision and movement time in these responses. If it had done so, estimation of the parameter $\underline{c}$ could have been more precise.)

3. The attributes of the terms, and the relationships between those attributes, are (whenever possible) controlled or manipulated in such a way that the appropriateness of completion terms can vary, and the processes of solution can be analyzed in terms of these attributes and relationships.

Component is the term Sternberg has chosen to use for what we have here called process, but Sternberg (1979) has analyzed the concept extensively and he would probably prefer the term because of the special properties he would wish to assign to it. Further, in his theory component is a concept that goes beyond the analysis of analogical reasoning; certain components are asserted to operate in analogy solution (see p. 70) but other tasks may require only some of these but require others in addition. A component is conceived to have both a duration and a probability of success. For example, one of the components in analogy solution is Inference, i.e., the inferring of a relationship between the terms A and B. This will take a certain amount of time (depending on the characteristics of the terms A and B, and individual differences), and the inference made can have a certain probability of being correct.

Although mathematical formulations of task processes similar to those of Sternberg have been made by others (e.g., Clark & Chase, 1972; Trabasso, Rollins, & Shaughnessy, 1971), the extent to which Sternberg has developed such procedures and applied them to analogical reasoning data is striking. By structuring the task in two phases and by manipulating the attributes and relationships of terms, he has been able to develop mathematical models which account for high proportions of variance in experimental data. Modeling is done in terms of both temporal and error probability parameters.

Sternberg has extensively studied three types of analogical reasoning tasks: the "People Piece" analogy, the verbal analogy, and the geometric analogy. Minor studies are reported on an "animal name" analogy task and the analogy items that occur in the standardized Miller Analogies Test.

The "People Piece" analogy involves cartoon-like drawings of "people" varying in four binary dimensions (tall/short, fat/thin, red/blue, and male/female). Combinations of these variables constitute the basis for a particular analogy item, for example, a tall, thin, blue, man (to express the drawing in verbal terms) is to a tall, thin, red, woman as a short, thin, blue, man is to a short, thin, red, woman (True). This rather contrived task is especially suited to model validation because the attributes of the terms can be better defined and manipulated than, say, in the case of the typical verbal analogy item such as HAND : FOOT :: FINGER : TOE. The geometric analogy task involves line drawings of geometric forms such as dots, squares, triangles, circles, etc. that can be combined in various ways to form analogies.

It would be impossible and gratuitous even to attempt to summarize the results of the extensive experiments reported by Sternberg (1977), and they have been commented on elsewhere (Carroll, 1978b; Pellegrino & Lyon, 1979). Further, Sternberg is engaged in a very active research program and has extended his componential analysis techniques to reasoning tasks other than analogies (e.g., Sternberg & Turner, 1978). We will limit ourselves mainly to the discussion of the People Piece analogy experiment and some of its outcomes, in order to explain componential analysis and provide a basis for certain comments. One outcome is estimates of the temporal parameters of components. For example, for the People Piece task, basic statistics of estimated parameters and component scores according to Sternberg's Model III are as follows (taken from Sternberg's Tables 7.9 and 7.10):

Component Score	Mean (msec)	S.D.	Intercorrelations and Reliabilities (underlined) (N = 16)				
			a	x	y'	z'	c
a (Encoding)	140	34	$\underline{.84}$	.10	.16	.11	-.60
x (Inference)	130	63	.10	$\underline{.91}$	.22	-.36	.10
y' (Mapping)	324	119	.16	.22	$\underline{.95}$	.27	.30
z' (Application)	154	75	.11	-.36	.27	$\underline{.85}$	.37
c (Preparation and Response)	452	162	-.60	.10	.30	.37	$\underline{.97}$

For an individual subject's data, these five parameters are found by solving for them in the following linear equations (adapted from Sternberg's Table 7.4):

$$\begin{aligned}
4a + fx + g'y' + f'z' + c &= ST_0 && \text{(0 cues)}\\
3a + fx + g'y' + f'z' + c &= ST_1 && \text{(1 cue)}\\
2a + g'y' + f'z' + c &= ST_2 && \text{(2 cues)}\\
a + f'z' + c &= ST_3 && \text{(3 cues)}
\end{aligned}$$

Although four equations are given here, actually the number of equations can be thought of as equal to the number of items or data points for which data are analyzed. The coefficient of a and the values f, g', and f' are determined for each item by the condition (number of cues) and the characteristics of the terms of the item and their relationships. The values ST_0, ST_1, ST_2, and ST_3 are the observed solution times (second phase reaction times) for an item, depending on the number of cues in the experimental condition. In effect, then, one is predicting the solution times, by familiar linear multiple regression techniques, from the characteristics of the items and the number of cues. A model of analogical reasoning, however, is needed to specify how to assign the values f, g', and f' to the items. We will not attempt to explain the Model III that Sternberg decided yielded best fits to the data, but the following information will give the reader some impression of how the model is formulated. The value f is the number of features (from 0 to 4) that are changed from term A to term B. In the example given above, 2 features change from A to B, i.e., color and sex. The value g' is the number of features, g, changed from A to C (in the example, only one, *viz*., height), but with an adjustment for the assumed "self-terminating" character of the Mapping component (process) when the analogy is false. In the example, the analogy is true and thus $g' = g$; we omit the details of the adjustment procedure. Similarly, the value f' adjusts f for the assumed self-terminating character of the Application process when the analogy is false.

Now, the basis of the equations can perhaps be more easily understood if we start by considering the 3-cue situation, which is described by the last of the four equations given above. The equation specifies the expected solution time when the subject has already been exposed to terms A, B, and C and has signaled readiness to be shown term D, which may be either correct or incorrect. Suppose it is correct. Then all the subject has to do in the solution phase is *encode* the final term D (taking the time a to do it), perform a self-terminating *application* process (applying to term C the inference rule he had previously derived from terms A and B, and taking the time $f'z'$ to do it), and finally prepare and make his response (taking the time c to do it). The time $f'z'$ is assumed to be controlled by a basic parameter z' multiplied by the coefficient f' which specifies the difficulty of the application process in the particular case.

Suppose there are only two cues, i.e., the subject has seen only the terms A and B before indicating readiness for the solution phase, in which terms C and D are shown. Here, the subject has to encode the terms C and D, taking time $2\underline{a}$ to do it (since a constant time for encoding a term is assumed over all terms). The remainder of the subject's task is what had to be done before, plus "mapping" term A onto term C--a process which takes time $\underline{g}'\underline{y}'$, which consists of a basic parameter $\underline{y}'$ multiplied by the coefficient $\underline{g}'$ which specifies the difficulty of the mapping process in the particular item.

Extending this explanation, one can see how the equations for the 1-cue and 0-cue cases are formed. For example, in the 0-cue situation, there are four terms to be encoded, taking time $4\underline{a}$, an inference process involving terms A and B and taking time $\underline{fx}$, the mapping and application processes already mentioned, and the constant preparation and response time.

In this light, componential analysis is an application of well-known multiple regression techniques; it involves, as we have said, the prediction of solution times from information on item characteristics and conditions according to a model that states how to specify item characteristics and take account of experimental conditions. As parameters solved for in the regression equations, $\underline{a}$, $\underline{x}$, $\underline{y}'$, and $\underline{z}'$ function like raw-score regression coefficients, and the parameter $\underline{c}$ functions like an intercept constant. When data are analyzed for an individual subject, these parameters are individual difference measurements; there is no inevitable experimental dependence, and there are no part-whole relationships inherent in the data. If the solution times were in no way related to the cue-conditions or the item characteristics as specified by the model, the expected value of the multiple correlation would be as predicted from the $\underline{F}$-distribution for the null hypothesis.

On the other hand, there is at least one sense in which a relationship exists in the data that could be expected to yield a substantial non-zero lower bound for the variance accounted for, namely, the fact that data points for the four cue-conditions are included in the regression analysis. As the cues increase from 0 to 3, the subject has processed an increasing amount of information in the cue phase, and has increasingly less information to deal with in the solution phase. Thus, the solution times would logically be expected to decrease, and thus to correlate "artifactually," as it were, with the coefficients of a in the basic equations. It appears that solution times do, in fact, decrease with increasing cues (this is inferred from examination of the data in Figure 7.3, p. 188, of Sternberg's book, although labeling of the four graphs by cue condition was inadvertently omitted in that figure). It was with this in mind that the writer, in a review of Sternberg's book (Carroll, 1978b), expressed some concern with the possible experimental dependence and "air of analysis of part-whole relationships" in Sternberg's componential analysis procedures. The robustness of the procedures can, however, be investigated by solving the equations separately by cue-condition. This would mean that in all cases the variance due to a would be absorbed into that due to c; the variance due to x could be estimated only in the 0-cue and 1-cue conditions, and that due to y' could not be estimated in the 3-cue condition. Nevertheless, whatever estimates are available can be compared over cue-conditions, and variation in the intercept constant would reflect the variation in cue-condition. (Sternberg has performed such analyses for both the People Piece and Verbal Analogy experiments, but only for the "full model" 0-cue condition; 1977, p. 197, p. 231. The percentages of variance accounted for were nearly as high as those achieved over the four cue-conditions.) Possibly my concern can be answered in part by the observation that in stepwise regression (shown in Sternberg's Table 7.5), the encoding parameter, which would be logically most affected by cue condition, was not the first parameter to enter the regression, but the third, coming after y' (Mapping) and x (Inference). However, a was the first variable to enter the stepwise regression in the Verbal Analogy experiment (Table 8.4, p. 234), with a correlation of .84 with solution times.

In the analysis of data for the People Piece experiment over all subjects, 92% of the variance was accounted for, an impressive amount. Just how much variance was accounted for on an individual subject basis is not reported, but the high reliabilities of the parameters, shown in our table above, would give credence to the supposition that these proportions of variance were high; the mean proportion of variance accounted for, over individual subjects, was 80.0% for Model III (Sternberg, 1977, p. 204).

Over subjects, the correlations among parameters are generally such as to indicate that they are practically independent, and that, as Sternberg notes, "[the components] are indeed distinct processes, and not repetitions of identical processes" (p. 205). There is some evidence (Sternberg's Table 8.7, p. 239) that the parameters generalize over tasks; over the People Piece and Verbal Analogy experiments, for example, significant correlations between corresponding parameters were .57, .59, and .79, respectively, for parameters $\underline{y}'$ (Mapping), $\underline{z}'$ (Application), and $\underline{c}$ (Preparation and Response Time). In both experiments, parameters exhibited some significant correlations with scores on reference ability tests of Reasoning, Perceptual Speed, and Vocabulary, although ultimate significance is at least a problem because of the small $\underline{N}$s ($\underline{N}$ = 16) on which the correlations are based. In both cases, the parameter $\underline{c}$ made the greatest contribution to the prediction of a Reasoning factor score; the correlation was -.71 for the People Piece experiment and -.77 for the Verbal Analogy experiment. I am assured (Sternberg, personal communication) that these correlations are unlikely to reflect a speed component in the reasoning ability tests because the scores on those tests, though timed, are practically identical to scores on the tests when they are untimed. In general, parameters did not show impressive correlations with Perceptual Speed. Sternberg (1977, pp. 211-217, 242-247) gives extensive discussion of these findings, considering a number of possible alternative explanations. He seems to favor the general proposition that high reasoning ability subjects have better strategies for solving the tasks, and are more systematic in their approaches. He is also able to claim, probably rightly, that the processes they use are those specified by the componential theory.

There are interesting differences between the results obtained with the People Piece experiment and the Verbal Analogy experiment. In particular, the parameter $\underline{a}$ (Encoding) was apparently much more influential in the latter; its mean value over subjects was 140 msec in the former and 323 msec in the latter, and Sternberg states

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(p. 235) that "more than half the amount of time spent on [verbal] analogies was spent in encoding, a clear increase from the People Piece Experiment." As Sternberg explains (p. 249):

> In the People Piece experiment, analogy items seemed to invite a systematic attribute-comparison strategy, at least in adult subjects: Attributes and attribute values were well defined, were constant over items, and could be sequentially sampled with a trivial attribute-discovery process. In the Verbal Analogy Experiment, neither attributes nor attribute values were well defined, and they changed from item to item. The subject must discover attributes, as well as test specific values of them. This discovery process, rather than the test process, may be the core of reasoning.

In Sternberg's work, then, the components are processes similar to those that have been postulated in the present monograph (explicitly in Chapter 2, and throughout our discussion). His componential analysis procedures could presumably be applied to RT and error data from many types of cognitive tasks, e.g., the Posner task, provided an appropriate model for assigning values of item characteristics can be specified. Application of componential analysis to the Posner task might, for example, resolve the issues we have raised concerning the independent significance of the NI-PI difference variable (see pp. 152ff.). Further, the parameters (component scores) derived through componential analysis can be entered into multiple regression, factor analysis, and other multivariate analyses involving different varieties of cognitive tasks. Of particular interest would be whether components isolated in particular tasks would be relatable to similar components isolated in quite different tasks. As far as we are aware, neither Sternberg's analogical reasoning tasks nor component scores derived from them have been included in any major battery of cognitive performance measures such that the components could be studied, by factor analytic techniques or otherwise, in relation to components of other types of variables.

In spirit, Whitely's (1977) approach to the study of analogical reasoning is similar to Sternberg's, in the sense that she has tried to dissect the reasoning process into stages or components, but, at least to judge from the study of hers that was selected for review here, one has to say that her experimental methodology gives far less precise and controlled results. She constructed a series of laboratory tasks intended to measure component stages in the solution of verbal analogies. Some of her tasks have already been considered under other rubrics, for example the Short-Term Retention task (see p. 210) and the Relationship Eduction task (see p. 195). Only four of her tasks, Relationship Choice, Relationship Evaluation, Relationship Study, and Analogy Completion After Study (the last two constituting actually a single task with two stages), involve full verbal analogies, but in each the data derived do not lend themselves to interpretation in terms of components as directly as do those of Sternberg.

Relationship Choice is essentially the same as the analogy task in Sternberg's 0-cue condition. Two complete analogy items are presented (all terms simultaneously), the first three terms being the same, and the last term being different--correct in one case and incorrect in the other. The subject's task is to examine the two analogies and decide which is correct. Total time to perform the task and the correctness of the choice are observed. Average time to make the correct choice was found to be 9.22 sec (S.D. = 5.06), but this time must include a considerable amount of redundant reading time; it is much longer than the typical solution time in Sternberg's 0-cue condition. In another task, Relationship Evaluation, subjects were asked to rate analogies on a 6-point scale that ranged from "Terrible" to "Excellent". Average rating time was 8.72 sec (S.D. = 3.66), but this probably includes substantial time in deciding how to make the rating even after the analogy was comprehended. The Relationship Study task was actually the first phase of a composite task of analogy solution; it was analogous to the cue phase of Sternberg's 3-cue task. The first three terms of an analogy (e.g., Deep : Cheap :: Shallow : _____) were presented with the instruction "study it until you understand what kind of alternative will complete it." Average time to do this correctly (as determined by correct completion of the second stage of the task) was 4.98 sec (S.D. = 2.02). This task is of interest because it explicitly asks subjects to predict the fourth term--at least the "kind" of alternative that is needed to complete the item. As we have noted, Sternberg's model did not take into account the possibility that an actual prediction of the result of the "Application" component could take place even in the cue phase of his task; the application component was assumed to operate only in the solution phase. Whitely's Analogy Completion After Study was the second phase of the analogy solution. Five alternatives were presented in a column as possible completions of the analogy whose first three terms had just been studied; for the example just given, these alternatives were:

(1) Costly
(2) Wide
(3) Steep
(4) Plenty
(5) Bargain

Average time was 6.73 sec (S.D. = 3.71). This task is analogous to the solution phase of Sternberg's 3-cue condition, but it is striking that even though the subject had presumably "predicted" the "kind" of completion needed, the average time was much longer than that needed, something less than 4 sec, by Sternberg's subjects in a roughly comparable situation. It would seem that the extra time taken by Whitely's subjects was spent largely in scanning the alternatives. The advantage of Whitely's procedure is that it represents an aspect of the standard multiple-choice format found in typical mental ability tests. For precise observation and analysis of reasoning processes, however, it is preferable to require subjects to make no more than a binary choice, or simply to require the evaluation of the correctness or incorrectness of one choice at a time.

Like Sternberg, Whitely used multiple regression to determine the role of components in analogy solution. Whitely's components were derived as the factor scores from separate factor analyses of latency and accuracy scores of the laboratory tasks. Since the laboratory tasks were separate tasks, any experimental dependence was avoided. Whitely found that number-correct scores on a standard analogy test could be predicted from three latency factors with a multiple $\underline{R} = .50$; the significant negative (-.41) and positive (.29) beta-weights in this regression for factor I (Memory Accessibility?) and factor III (Decision Time), respectively, seem to mean that high scoring is associated with rapid memory access and slow (deliberate?) decision time. In the prediction of number-right scores from the accuracy factors, only factor I had a significant beta-weight (.66); this finding, however, contributes very little understanding because it suggests merely that the "evaluation" aspect of analogy solution can be isolated in laboratory tasks that focus on this aspect. The net result of Whitely's study can be summarized by saying that verbal analogy solution involves largely uncorrelated factors of speed and accuracy, but exactly what these factors are could be elucidated only in further research.

ECTs Classified Under Paradigm 8 (Algorithmic Manipulation)

Under this category we consider several cognitive tasks that have resisted classification elsewhere because of their apparent complexity in the sense that they seem to involve a series of operations on mental representations, as well as, in some cases, the manipulation of representations according to rules or algorithms stored in long-term memory.

One of the simpler of these complex tasks is the Three-Term Series task used by Lansman (1978) in her study of individual differences in performance in a dual-task setting. It is surprising that despite the attention devoted to this task in the experimental literature (Clark, 1969; Huttenlocher, 1968), it has received little attention from an ID standpoint and appears only in Lansman's study, among those surveyed here. In Lansman's version of the task, subjects were presented with problems like

A ABOVE B
B ABOVE C
TOP?

the task being to press answer buttons A, B, or C according to the correct answer. The terms were always A, B, and C; the prepositions either ABOVE or BELOW; and the question word either TOP or BOTTOM. (Note that a vertical orientation of the representations is implied; a horizontal or neutral orientation could be specified, for example, by using the prepositions BEFORE and AFTER and question words FIRST and LAST.) Feedback ("RIGHT" or "WRONG") was given after each response. There was complete or simultaneous presentation of the problem as a whole (as opposed to several ways in which there could have been successive presentation of premises and question). Reliabilities of correct response RTs and error proportions over 4 blocks of 16 trials each were .96 and .76, respectively. The relative complexity of the task is reflected in the mean RT (for correct responses only) of 5441 msec (S.D. = 1622); the distribution was probably positively skewed since minimum and maximum RTs are given as 2930 and 10003 msec. Statistics for per cent errors, also apparently positively skewed, are Mean = 8.4, S.D. = 6.4, ranging from 0 to 28.1. RTs and errors correlated only .25 with each other, and the correlations with the verbal composite of the Washington Pre-College (WPC) test were -.37 and -.22, respectively. Lansman remarks (p. 74) that these results disconfirmed her expectation that the series task, being more complex than the Sentence Verification task, would correlate more highly with the WPC. Nevertheless, in our factor analysis of her correlations, the RT variable appeared with a loading of .73 on factor LANB-A, Speed of Semantic Processing, which had a loading of .59 for the WPC. In view of the debate in the experimental literature as to the relative importance of verbal and spatial coding in the performance of this task, it seems likely that this is a task for which an interaction between verbal and spatial ability might be demonstrated, somewhat analogous to that demonstrated for the Sentence Verification task by MacLeod, Hunt, and Mathews (1979). Differences in abilities and/or strategies may have been responsible for the low correlation of the RTs with the WPC. The Three-Term Series task should be further studied with this possibility in mind, preferably with successive presentation techniques.

In our factor analysis, the error variable appeared, weakly, on factor LANB-C which we interpret as Accuracy of Semantic Information Processing. Apparently there is a considerable amount of specific variance in this variable, although it had a correlation of .72 with the error variable on the Sentence Verification task.

Hitch (1978) reported experiments with a Mental Arithmetic task in which subjects are auditorily presented with pairs of multi-digit addition problems such as 325 + 46 to do "in their head". In performing this task mentally, subjects report breaking down the problem into a series of stages, but they differ somewhat in the order of carrying out operations. The modal pattern is to deal first with the units, then with the tens, then with the hundreds, but not even the majority of Hitch's subjects used this pattern; there were several other patterns, depending in part on the "carrying" requirements of the addends. Possibly individual differences in the way in which such patterns are used are a result of experience and training and are not of immediate interest in the study of cognitive abilities. Hitch was more interested in using this task in the study of working memory; by having subjects use different patterns (hundreds, tens, units vs. the reverse) he was able to show that interim information built up in the course of task performance is forgotten if not utilized immediately. Also, Hitch formulated and tested a decay model of working memory storage.

Allen, Rose, and Kramer (1978) adapted Hitch's task for use in their study of IDs in a variety of memory tasks. Instead of timing subjects' performances, they used a "deadline" condition in which problems were read to subjects auditorily at the rate of one every 5 sec. Subjects had to write down as much of the answer as they could in blanks representing the hundreds, tens, and units positions. The investigators classified the problems in terms of memory load. Depending on the numbers of digits in the addends (3 & 3 or 3 & 2) and the number of carrying operations required in the respective positions, memory load of items could vary from 5 to 8. They determined that task performance, measured either in terms of the number of positions marked with correct digits or in terms of the number of positions left blank (uncomputed), was systematically (and approximately linearly) related to memory load. Each subject was then assigned intercept and slope parameters for the functions relating number-correct score and blank-position score to item memory load. Unfortunately, the reliabilities of these parameters were low, ranging from .14 for No. Correct Intercept to .61 for No. Blanks Slope. In our factor analysis of these data, we used only No. Correct Slope and an overall Mean Correct, which correlated with each other only .55 despite their experimental dependence. These two variables defined a factor ALRK-F, which probably has to be interpreted as a specific factor for this task, since the patterns of factor loadings of other variables on the factor do not appear amenable to ready interpretation. There are some indications that variance on the Mental Arithmetic task variables is associated with factor ALRK-B, tentatively interpreted as a Memory Span factor. If measures of numerical facility and numerical reasoning had been included in Allen et al.'s battery, it is likely that some of the variance in the Mental Arithmetic task would have been shared with one or both of those factors. Further study of the mental arithmetic task, varying the conditions under which it is administered and exerting more control on subject strategies, might be profitable for defining its content more precisely.

An even more complicated algorithmic task is that studied by Hunt, Lunneborg, and Lewis (1975), the so-called "Sunday + Tuesday" task. Subjects are given a stimulus such as a day of the week, a month of the year, or a letter of the alphabet, and required to convert it (mentally) into a numerical representation by a rule (e.g., Sunday = 1, Tuesday = 3; October = 10; W = 23; etc.). Time of this encoding is observed in a first stage of the task. Upon presentation of another stimulus in the same class, they convert it to a numerical representation by the same rule, add the number to the previous number, and then convert back to the original stimulus class with the modulus of the stimulus class size; e.g. October + April = February. Solution time and any errors in the second phase are observed. A number of variables can be derived from task performance, taking account of class sizes (7, 12, 26) and any "carry" operations. Hunt et al. found that verbal ability as measured by the Washington Pre-College test was correlated with a number of these variables, particularly with those derived from the solution phase of the task. Further, several variables from this task were large contributors to the definition of factor HULL-A in their factor analysis, interpretable as some kind of general intellective factor since it also had loadings for a number of psychometric tests--Verbal Reasoning, Space Visualization, Numerical Reasoning, Verbal Comprehension, Numerical Ability, and Hidden Figures. It is not clear to what extent this factor represents intellectual power as opposed to speed, however, or to what extent the loadings for the Sunday + Tuesday task reflected the speed as opposed to the power or difficulty aspects of this factor.

The Raven Progressive Matrices test, in its various forms, can be viewed as a series of tasks requiring algorithmic manipulations of mental representations. The subject must examine a matrix of visual figures and infer the principles by which the figures change over rows and columns, applying these principles to decide which of a number of alternative completions will satisfy them. In some respects, the task resembles the Geometric Analogy task studied by Sternberg (1977). As Lunneborg (1977, p. 318) notes, "The Progressive Matrices test is variously considered a measure of general intelligence, an indicator of a reasoning factor, Induction (I), or a 'space' measure." Lunneborg reports doing a factor analysis of Progressive Matrix scores along with various spatial tests and finding two clusters, one of which contained the Progressive Matrices score. Progressive Matrices items were then studied as laboratory tasks, items being presented individually and solution times being recorded for each figure. According to Lunneborg, "Principal components analysis of these time scores produced two components based respectively on earlier and later problems in the set" (p. 320). It is not clear whether these two components arose as factors associated merely with differential difficulty or as factors indicating different processes associated with easy and difficult items. In any event, in a further factor analysis the two speed components defined a single factor (Lunneborg, 1977, Table 5, p. 322). Yet only the component associated with the easy items (Raven Time I) showed any significant correlations with psychometric measures: -.30 with Space I and -.36 with Space II (which included the number correct scores on the Raven test).

In a further study, number correct scores on Set II of Raven's Advanced Progressive Matrices were used as criteria against which to evaluate the contribution made by a series of information-processing measures. Only 11% of the variance of these scores was predicted by the information processing measures, possibly because, as Lunneborg remarks, the information processing measures constituted only a fairly limited set, composed of the Visual Temporal Order Judgment task, a Dichotic Listening task, a Delayed Auditory Feedback task, and the R/L Conversion task. At the same time, however, these measures predicted about 24% of the variance of solution times for the more difficult Raven task problems (Lunneborg, 1978).

Because of its importance and wide-spread use, it would be important to study the Raven task through componential analysis or a similar procedure, and in conjunction with a well-defined battery of information measures tapping the variety of cognitive processing variables that have been identified, albeit tentatively, in this review.

Chapter 5

POSSIBILITIES FOR OPERATIONAL APPLICATIONS OF ECT MEASUREMENTS

Introduction

The preceding two chapters have provided, in effect, an introduction to what may be seen as a relatively new field of differential psychology. Mainly through correlational, factor-analytic, and task analysis procedures we have tried to delineate the rough outlines of a broad domain of individual differences in what we call Elementary Cognitive Tasks (ECTs). In some respects that domain is undoubtedly different from that covered by conventional psychometric tests and procedures. A large number of apparently rather specific abilities have been defined, at least to a first approximation, that have not been readily measurable by conventional tests. At the same time many of them probably function in the performance of conventional tests and make some contribution to their variances.

In this chapter we give some thoughts on the possibilities of developing operationally useful measures of the abilities tapped by ECTs, and consider their relations to selected dimensions defined by conventional measures of mental ability. Also, we consider the possible "validity" of such measures in operational use--in personnel selection and training, in assessing the effects of physiological and psychological stress, and in studying the changes in mental functioning that may occur with increasing age.

Data for supporting these observations and speculations are generally very limited. For assessing the possible reliability of measures, we need many more studies using repeated measurements over periods of time. Among the 55 studies that have been the focus of this survey, only 5 yield any such data, but the periods of time are never more than one week. Allen, Rose, and Kramer (1978) present test-retest data from 2 sessions scheduled "a day apart." Chiang and Atkinson (1976) report reliability data based on their having conducted repeated tests in 4 sessions "spread over one week." Fernandes and Rose (1978) gave two sessions "two days apart." Rose (1974) had sessions on "three consecutive days." Rose and Fernandes (1977) had two sessions "scheduled two days apart." While test-retest reliabilities for materials given on two separate sessions are useful, it is only the data from three or more sessions that are useful in assessing whether reliability increases or changes with practice. Repeated measurements data are also useful for appraising whether the factorial composition or construct validity of measurements changes with practice or other temporal effects.

Data on the operational validity of ECT measurements are even more meager. While a number of studies have attempted to relate ECT measurements to those tapped by more conventional psychometric tests (see Table 1, pp. 75-80), we find only two studies (Cory, 1977; Love, 1977) concerned with the predictive value of ECT and other measures for training or on-job performance. There is a considerable literature on the use of certain ECT measurements in the assessment of physiological and psychological stress and in the study of age changes, but we have not attempted to review it in detail here, hoping that researchers concerned with those areas will find some profit in studying what is presented in this review.

In addition, the data available for assessing the operational potentialities of ECT measurements frequently suffer from the usual limitations--small Ns of samples, restriction of samples to college-going or other special populations, incomplete reporting of procedures, analyses, and results, etc.

Promising Dimensions of IDs in ECTs

In this section we take up domains and dimensions of IDs in ECTs that we have identified in the previous two chapters either by factor-analytic or task analysis procedures, commenting on their promise as a basis for the development of measures that may have significant uses in research or in operational contexts of various kinds. Where it seems appropriate to do so, and relevant data are available, we consider the extent to which individuals appear to differ on a persisting basis, practical matters in developing efficient measuring procedures, the question of what kinds of dimensions are tapped by testing relatively unpracticed subjects as opposed to the testing of highly practiced subjects, the problems in scoring or otherwise deriving measures of performance, and the extent to which tasks are open to the operation of different strategies on the part of subjects. The treatment of these matters is necessarily rather cursory and superficial; much more space would be needed to deal with them intensively. Our purpose is mainly to summarize material surveyed here in such a way as to indicate suggested directions of emphasis in future research.

IDs in Basic Perceptual Processes

IDs in sensory capacities, that is, in absolute and differential thresholds in visual, auditory, and other modalities, are well recognized and have been the subject of extensive study, and there exist standard procedures for measuring these capacities (visual acuity tests, audiometric tests, etc.). IDs in related cognitive capacities involving the apprehension and perception (identification of) external stimuli have received much less attention. Conceptually, possible dimensions of IDs can be formed by crossing modality with assumed cognitive processes such as apprehension (APSTIM) and perceptual integration (CLOZR) and with types of contents to be perceived, such as geometric forms, pictures, and printed symbols, in the visual modality, and noises, tones, and spoken language elements in the auditory domain. As indicated previously (pp. 87-89, 122-127), IDs have been found for certain kinds of perceptual tasks, but little is known about either the short-term or long-term reliabilities of these IDs. Also, little is known about the extent to which basic sensory capacities are involved in the variances. One can only speculate as to whether such elementary cognitive capacities are of theoretical or practical significance, but it is conceivable that they are, as basic parameters of cognitive functioning at the sensory-perceptual level. It would appear that measures of such functioning would be very little subject to effects of practice or to the effects of different subject strategies, because the processes are largely automatic and out of subjects' awareness or control.

Since nearly all experimental measures of IDs in ECTs involve visual or auditory presentation, with consequent involvement of any important parameters of sensory and perceptual processes, it would seem imperative to have more knowledge of this domain, and to develop measurement procedures that would have known properties with respect to norms of performance in different populations and with respect to short-term and long-term reliability. At the present time, no such measures are available, although approximations of them are to be found in the psychometric literature in the subdomain of perceptual closure (Ekstrom, French, & Harman, 1979, pp. 9-13). Perceptual closure tasks need to be given more attention in experimental studies, however.

Measurement of apprehension and perceptual integration processes generally requires fairly elaborate individualized testing procedures, e.g. with the use of tachistoscopic presentation and applications of the method of limits. With computer-controlled testing, this should not present a problem. It may be pointed out that standard audiometric procedures involve automated method-of-limits testing; analogous procedures might be possible in testing elementary perceptual processes.

IDs in Reaction and Movement Times

IDs in several dimensions of performance in simple and choice reaction time tasks have been identified (see pp. 89-92, 127-137). Of these, the more cognitively loaded are: Simple reaction time (which applies also to baseline of choice reaction time performance), Slope of Choice Reaction Time as a Function of Amount of Information, Reaction Time to Complex Sequential Events, and Accuracy of Complex Information Processing. High internal reliabilities have been claimed for the first two of these, with some evidence of long-term reliability as well. Also, there are claims (Jensen, 1979; Lunneborg, 1977) that these dimensions are related to performance on conventional mental ability tests. The last two of the factors or dimensions just named are based on our reanalysis of a single study (Robertson-Tchabo & Arenberg, 1976); that study does not report reliabilities, but the high communalities found for some of the measurements are evidence for satisfactory reliability. The special interest of these dimensions arises from the fact that they appear in performance of what may be termed a vigilance task in which the subject has to respond only to certain events occurring in a continuous series of auditory stimuli. Considerable cognitive load can be imposed in this task, giving rise to the accuracy factor. The possible relations with other dimensions in this domain remain to be investigated. Accuracy aspects of simple and choice reaction time have not been adequately investigated, although error rates are generally low.

Also identified in this domain are two dimensions that refer to aspects of task performance in which cognition probably plays little role, but that must be taken account of if accurate measurements are to be obtained on other aspects of performance (whether in the reaction time domain or in other domains involving measures of reaction speed). One of these is Hand Movement Speed, or simply Movement Time, independently observable only if the experimental procedure distinguishes it from decision time. There is some evidence (Jensen, 1979; Welford, 1977) for its being a reliable, important, and persisting dimension of IDs despite its seeming non-cognitive character. Evidence for the other dimension, Fine Motor Hand Control, is limited but it may be relevant in the evaluation of certain paper-and-pencil tasks that require the rapid and accurate manipulation of marking instruments to reach target spaces.

Finally, at least two promising dimensions arise from recent studies using reaction time methodologies: Flexibility of Attention and Time-Sharing Ability (or Abilities). (Recently come to hand is a study of time-sharing abilities by Hawkins, Rodriguez, & Reicher, 1979.)

Measurement of all these dimensions is probably best done with computer-controlled equipment involving visual and/or auditory displays and special response devices. Available research reports make little if any mention of alternative strategies open to subjects in performing reaction time tasks, and it would appear that only limited amounts of practice are needed before subjects reach asymptotic levels of performance.

IDs in Various Mental Comparison and Recognition Tasks

A number of relatively independent dimensions of IDs can be identified in a variety of tasks requiring subjects, among possibly other things, to make rapid comparisons of visual stimuli or comparisons of visual stimuli with memorial representations of stimuli. (The domain of analogous auditory comparisons has not been explored in the experimental literature surveyed here, although auditory stimuli are occasionally employed to evoke representations to be compared with visual stimuli.)

One dimension yielding striking individual differences and high reliabilities of measurement can be identified as Speed of Visual Mental Comparisons. Subjects differ reliably in the rapidity with which they can report the positive or negative result of a comparison of two visual stimuli, presented without angular rotation or other transformation, and regardless of the type of stimulus, or compare a visual stimulus with some memorial representation of a stimulus. This dimension appears most strongly in the "physical match" phase of a Posner-type task or in the intercept parameter of a Neisser-paradigm visual search task or of a Sternberg-paradigm memory search task. It can appear, however, in other aspects of the performance of such tasks, for example in Posner-paradigm tasks requiring comparisons of stimuli with respect to names or symbolic values of stimuli, particularly when the stimuli are actually physically the same. Evidence suggests that subjects must be quite well practiced before reliable IDs appear, or at least that performance may reflect somewhat different abilities in later as opposed to early stages of practice. At early stages of practice, reaction times may be more influenced by basic differences in the simple reaction time dimension than at later phases, when this other dimension, speed of visual mental comparisons, begins to be dominant. There is also evidence that for more complex types of stimuli, such as dot patterns or complex visual shapes, subjects differ in the strategies they may employ in making comparisons ("holistic" or "structural" vs. analytic) and/or the extent to which they are prone to access name or other symbolic codes in the comparison of two stimuli. Much more research is needed to clarify the conditions under which different strategies can exhibit themselves. The possible connections between this factor and reading performances need particularly to be clarified. On the one hand, it is possible that IDs in Speed of Visual Mental Comparisons betoken constitutional differences among individuals that contribute to differences in reading ability; on the other hand, it is possible that differences in this dimension are mainly attributable to differences stemming from different amounts of practice and exposure to reading. Currently available evidence does not permit a firm judgment as to which of these possibilities is more likely, or whether both possibilities must be considered.

Correlationally independent of visual mental comparison speed, but logically closely related, is a factor or dimension that we identify as Slope of Visual and Memory Search. It arises in Neisser- or Sternberg-paradigms in which the subject must search for a target either in a physically present visual display or in a memorial representation of such a display. The slope parameter in which the IDs are manifested represents the rate at which separate items in the array are searched. From evidence on test-retest reliabilities over days, it seems that IDs in this dimension are likely not to be well measured until the subject has had a considerable amount of practice in a task that measures them. Normally this dimension is measured through individualized testing in a laboratory setting, but valid measurement can be achieved through certain adaptations of tasks to a paper-and-pencil format.

Slope of Visual and Memory Search is clearly independent of Speed of Visual Mental Comparison, but its relation to the (normally) psychometrically defined Perceptual Speed factor is as yet unclear, since Perceptual Speed also seems to reflect rates of search through visual arrays. The Perceptual Speed factor that can be identified in a variety of ECTs apparently contributes at least one facet of the psychometrically defined Perceptual Speed factor.

Two other factors in this domain, with as yet undetermined relations to those already mentioned, have specifically to do with mental comparisons involving rotations or change of perspective of visual displays. These factors are identified, respectively, as Spatial Speed and Spatial Accuracy. Spatial Speed is measured through latencies of comparisons of physical stimuli where it is necessary for the subject to imagine how one of the stimulus arrays will appear from a different perspective from that presented. Spatial Accuracy has to do with the probability that such a comparison will be correct, and is independent of Spatial Speed. As yet it is undetermined how either of these factors relates to the three factors that have been identified in the "spatial" domain through psychometric tests as Spatial Relations, Spatial Orientation, and Visualization (Lohman, 1979a), mainly because the tasks are often susceptible of being solved either by "mental rotation" of stimuli or by the subject's imagining himself moving to a different position for viewing the stimulus.

Two other dimensions in this domain are separate and independent speed and accuracy factors having to do with the processing of semantic information, as in the comparison of two linguistic representations or the comparison of a linguistic representation with a pictorial one. Available evidence suggests that these factors are independent of the dimensions already mentioned, and that neither factor has necessarily to do with extent of vocabulary or linguistic knowledge, since the factors are components of tasks employing linguistic materials that are well within the linguistic knowledge of the typical subject. Instead, Speed of Semantic Processing reflects individuals' latencies in handling semantic information, and Accuracy of Semantic Processing indicates their ability to handle this information without error when pressed to do so rapidly. (Probably these factors can be efficiently measured only when a speed-accuracy tradeoff favors speed.) Considerable practice on semantic information processing tasks seems to be required to reveal reliable individual differences. Different subject strategies have been demonstrated to operate in sentence verification tasks.

Of possible relevance in this domain is the relatively specific variance observable in accuracy scores or in certain parameters derived from a running recognition task in which the subject has continually to evaluate whether a presented stimulus (of any type) is an "old" stimulus previously presented in a series of such stimuli, or a "new" stimulus not previously presented in the series. The status of any IDs in the latencies of such evaluations has not been investigated

IDs in Tasks Requiring the Retrieval and Production of Names and Other Responses from Semantic Memory

Although not yet extensively studied in relation to other dimensions of cognitive IDs, a dimension of reliable individual variation in spoken object- or picture-naming latencies appears to exist independently, reflecting speed in retrieving names from semantic memory upon the presentation of stimuli evoking those names. Since average latencies are significantly correlated with age over the period of adulthood and later life, and are also affected by the age of acquisition of the names in early life, naming speed may be a reliable indicator of an important aspect of cognitive functioning with respect to the mastery of the semantic memories that an individual has acquired over a lifetime. Precise measurements are obtainable only with tachistoscopic presentation of stimuli and timing of separate responses, but approximate measurements can be obtained with simpler formats such as timing an individual's naming of a series of pictures. There is no evidence that there are reliable IDs, independent of basic picture naming speed, in the rate at which individuals achieve asymptotic levels of performance with repeated trials; therefore, it is sufficient to take measurements upon the initial presentations of stimuli.

As far as is known, latencies of naming letters, words, and other visual linguistic symbols (i.e., "reading" them) constitute a dimension of IDs that is relatively independent of any thus far mentioned, although some evidence suggests that Speed of Mental Comparison is relevant here, possibly by virtue of the fact that letter or word comparisons are often involved in mental comparison tasks such as the Posner-paradigm.

A further dimension in this subdomain may be represented by speed parameters derived from the so-called Stroop Color-Word reading task, in which the subject's difficulty in naming the colors of words representing colors other than those in which they are printed is evaluated. The relation of this dimension to picture-naming or word-naming dimensions is as yet unclear, but some evidence suggests that the dimension is complex and contains some variance related to a general mental ability factor.

Word-naming or reading ability can be broken down into several relatively independent subdimensions, having to do with the extent to which the reader (1) has rapid access to letter recognition codes, (2) makes efficient use of the regularities of the orthography of the language, (3) is able to apply spelling rules to derive a phonemic representation, (4) can efficiently translate that representation into a spoken utterance, and (5) is able to recognize common words by a visual whole-word strategy. These separate dimensions of reading skill may be of importance in the teaching of reading and in the diagnosis of reading disability. The extent to which any of these separate abilities may be related to dimensions mentioned earlier is unclear; one or more of them may be related to dimensions mentioned under IDs in mental comparison and recognition tasks.

IDs in Episodic Memory Tasks

There appears to be a general factor of memory, i.e., the ability to register any kind of material for later recall and then to retain it without severe decay for later recall. Besides this general factor, the nature and operation of which is not well understood, there are a number of separate dimensions of memory ability that can be identified and measured through special techniques.

One of these dimensions appears to be memory for the spatial or temporal order in which a series of readily identifiable memory stimuli is presented, apart from memory for the individual identities of the items.

Two further dimensions have to do with the capacity to register and recall the identities of items or units in a memory task--whether it be a memory span task, a free recall task, or some other kind of task. In the case of one of these dimensions, it is the ability to register and retain material in "primary" or immediate working memory; the other of these dimensions is the ability to retain materials in "secondary" or delayed memory, despite possible interference from intervening events such as the presentation of new material for memorizing or the requirement to turn attention to some other type of activity such as counting numbers backwards by 3's.

Still another dimension arises particularly in connection with paired-associate memory tasks, in which the critical element is remembering the particular associations between "stimulus" and "response" terms that have been established in the presentation of the task.

Two other dimensions apparently have to do with (1) the ability to "tag" items as having some arbitrary feature such as "correctness," as in a verbal discrimination task, and (2) the ability or inclination to make note of memory materials as "events" or items of some special interest or significance.

For all the dimensions mentioned above, accuracy of recall, rather than speed or latency of response, is at issue, and the task administration and scoring procedures do not require excessively elaborate apparatus. (The speed or latency aspects of these memory abilities do not appear to have been investigated.) Only minimal prior practice of tasks is needed for reliable measurement of performance, provided that the tasks involve appropriate amounts of material to be memorized, or appropriate numbers of trials, to achieve satisfactory reliability. Most of the tasks can be given on a group testing basis. Although some of the tasks are susceptible to the application of different strategies on the part of subjects (e.g., clustering by semantic or other categories), there is little evidence that such strategies constitute important independent sources of individual differences or that they can be reliably measured.

IDs in Reasoning and Algorithmic Manipulation Tasks

Little attempt will be made here to identify promising dimensions of performance in reasoning and algorithmic manipulation tasks because it is our feeling that at least some such dimensions are included in those already mentioned. This feeling is supported, to a considerable extent, by our analyses of relations between parameters of these tasks and parameters of the simpler ECTs. Thus far we have little basis on which to make firm cross-identifications of R. Sternberg's (1977) "components" of analogical reasoning tasks with the dimensions of IDs that we have identified above as promising for further research and operational development. Actually it seems likely that the nature of some of Sternberg's components varies with the nature of the reasoning task. For example, the Encoding component may have a different character depending on whether it involves pictorial stimuli, as in the People Piece analogy task, or verbal, printed material, as in the Verbal Analogies experiment. The intercorrelation of this parameter between the two experiments, performed by a common subject sample, was only .25. (See further discussion below, p. 277.)

On the other hand, Sternberg's Preparation and Response parameter (c) does appear to have stability over tasks and it may be relatively independent of dimensions described above. It is clearly related to reasoning ability as measured by a variety of psychometric reasoning tasks. Because of its possibly superior construct validity, this parameter may be offered as a promising one to develop for operational use. Its major disadvantage is the rather complicated task administration and scoring procedures required to obtain it.

Relationships with Psychometric Tests

As already stated, dimensions of IDs in ECTs undoubtedly contribute to the variances of scores on "traditional" or "conventional" psychometric tests. One would expect this to be true, if only because the "items" contained in psychometric tests are often, in effect, ECTs (Carroll, 1976a), and whatever scores are derived from psychometric tests will therefore reflect, in varying amounts, speed and accuracy aspects of ECT performance. The major virtue of deriving ID dimensions from ECTs rather than from psychometric tests is that greater control of the conditions of task performance and greater precision in the measurement of separate aspects of performance can be achieved.

It has long been known that scores on psychometric tests administered under time-limit conditions contain both "speed" and "power" (or "level") components, although this fact is not always recognized by test users or even researchers. Conventional administration and scoring procedures take little account of it. Because Lohman (1979a, pp. 151-187) has recently reviewed the literature pertaining to speed and level components of psychometric tests (particularly as it relates to spatial ability tests), it will not be reviewed here. Suffice it to say that in many domains of ability, speed and accuracy dimensions of performance are clearly distinguishable, and that the correlations between them may range widely, even into negative values. Speed and accuracy dimensions are difficult to measure separately with conventional tests, and variations in item difficulty and complexity affect their relationships. Raw or derived scores from most psychometric tests simply fail to convey requisite information about relative contributions of speed, level of accuracy or mastery, and item complexity to total test performance. Egan's (1978) demonstration of the possibility of recasting spatial ability tests into better formats for measuring separate speed and accuracy aspects may be cited as a guide and inspiration for similar research efforts in other domains of ability. Lohman (1979b) has proposed and illustrated a method of handling the additional complications introduced by variations in task complexity, together with speed and level.

This matter of speed-level-complexity relationships will plague us seriously as we attempt to look at the reported relations of ECT measurements with scores from psychometric tests. There has been much interest in relations of ECT measures with such measures of intellectual ability and "scholastic aptitude" as the College Board's SAT-V and SAT-M scores and the University of Washington's Pre-College Test that has been used extensively by Hunt and his colleagues (Hunt, Frost, & Lunneborg, 1973; Hunt, Lunneborg, & Lewis, 1975) and Lansman (1978) to define groups of different "verbal" and "quantitative" abilities. Information on the degree of speededness of the SAT is provided by Donlon and Angoff, as follows:

> The SAT is intended to be basically a power measure, and its evolution over the years has called for increasing amounts of time per item for both SAT-V and SAT-M. . . . As in any timed test, however, speed is inevitably a factor, however small. In the factor analysis studies of Coffman (1966) and Pruzek and Coffman (1966), both SAT-V and SAT-M were found to contain clear speed factors which seemed to account for about 9 percent and 4 percent of the total variance, respectively. (Donlon & Angoff, 1971, p. 29)

From 1926 to 1958-69, the time allowed per item went from 20 sec to 50 sec for verbal sections; for the mathematical sections the figure went from 14 sec to 75 sec. Donlon and Angoff present further data on the speededness of the tests at 12 administrations over the period December 1966 to May 1969 that we may summarize as follows:

	SAT-Verbal		SAT-Mathematical	
	30-min sections	45-min sections	30-min sections	45-min sections
Mean percent completing test	73.8	68.2	54.1	83.6
Percent completing 3/4 of test	99.6	98.9	95.4	98.2
Mean number of items not reached	0.96	1.66	1.48	0.67

Whether comparable data are available on the University of Washington Pre-College Test, we do not know, but one may assume that its construction and characteristics are roughly comparable to those of the SAT. If 9 percent of the variance of SAT scores is attributable to speed independent of level of accuracy or mastery, a perfectly reliable measurement from some type of ECT performance could have a correlation with SAT total score as high as .30 in absolute magnitude, and still have no involvement with the power component. Of course, perfect reliability in an ECT speed measurement is unlikely. The basic point is that finding a correlation of some ECT measurement with an SAT or WPC score (or any other measure of general ability) gives no indication of the respective correlations with speed and level components of the scores. Much of the correlation could be attributable to common speed elements. Only through special kinds of test administration procedures and data analyses could one obtain indications of the relative contributions of speed and level components.

It is entirely possible that ECT variables that correlate significantly with SAT or WPC scores are related, in part or even in whole, to the power or "level" components of such scores, through involvement in both sides of the correlation of either some kind of broad intellectual ability or fairly specific components of verbal ability, reading comprehension, or vocabulary. Reading comprehension figures in SAT performance, and it has been shown that extent of vocabulary is an important element measured by the SAT-V; word-frequency data on words that are critical in item performance are highly predictive of item difficulty indices (Carroll, 1979). ECT measurements of speed and efficiency of cognitive functioning may be indicants of people's ability to acquire highly efficient reading skills or to acquire an extensive vocabulary. Nevertheless, logic and general experience with correlations of intellectual abilities suggest that speed or latency measurements from ECTs are more likely to be correlated with the speed than with the power components of SAT or WPC scores, when the correlations with total scores are significant. Even if this is the case, the correlations need not be regarded as of trivial importance because the speed components of scholastic aptitude tests may, for all we know, play some role in the effectiveness of such measures in whatever functions they may have in college admissions and other educational decisions. For example, Lord (1956) found speed scores positively correlated with academic grades at the U.S. Naval Academy.

One might think that some tentative conclusions about speed and power relations of ECT measurements with intellectual and scholastic aptitude tests could be drawn from an examination of what kinds of ECT dimensions exhibit correlations with scores from those tests. However, even a cursory look at the data available will show that limited numbers of cases in studies, limited data from psychometric tests, failure to consider sex differences, and the as yet insufficient information about dimensions of ECT performance make the task of drawing any conclusions almost hopeless at this time.

First indications that ECT measurements might have correlations with scholastic aptitude measures arose from the study by Hunt, Frost, and Lunneborg (1973), who reported differences in a variety of ECT measures between small groups of students selected from the top and bottom quarters of verbal and quantitative score distributions of the (University of) Washington Pre-College test (WPC), a test which the authors characterize as for all practical purposes equivalent to the SAT. Significant differences were noted for certain parameters derived from the Continuous Paired-Associate test and for performances in free-recall tasks, the Posner physical vs. name match task, a Brown-Peterson memory interference task, and certain paired-associate tasks. Some of the differences were associated with verbal scores, others with quantitative ability scores. The authors interpreted the findings as indicating that verbal ability is associated with rapid access to short-term memory, and that quantitative ability is associated with resistance to interference with cognitive functioning. Insofar as different patterns of results were obtained for verbal and quantitative scores, and in view of the fact that verbal and quantitative ability are substantially correlated with each other and also the fact that their measurements both contain speed components, the results argue somewhat against the hypothesis that the ECT performances were specifically related to speed components of the WPC. It is unfortunate that the authors did not report a correlation matrix that included WPC scores so that factor-analytic procedures might provide some indication of how they were related to ECT variables.

In a later and somewhat larger study--but with little increase in sample sizes (Hunt, Lunneborg, & Lewis, 1975), the earlier results were at least partially confirmed.

It was reported that "university students who obtain high scores on a conventional test of verbal ability [the WPC verbal composite] do unusually well on a variety of CIP [Current Information Processing] tasks," and it was concluded that "although a verbal intelligence test is directly a measure of what people know, it is indirectly a way of identifying people who can code and manipulate verbal stimuli rapidly in situations in which knowledge per se is not a major factor" (p. 223). Nevertheless, the results reported do not exclude the possibility that ECT differences between high and low verbal subjects were associated primarily or exclusively with speededness aspects of the WPC and other psychometric tests, and the authors' conclusion just quoted seems to direct attention to the speed element that is common to the ECT and psychometric variables. The factor analysis of psychometric and ECT variables reported by these authors can be interpreted as indicating that psychometric intelligence is largely independent of many types of ECT variables.

In a theoretical article, Hunt (1978) has stressed, however, that large differences in ECT performances, especially in the Posner matching task and the Sternberg memory search task, can be observed between "normal" groups and extreme groups such as encephalitic mental retardates and "senior citizens." This poses the problem, however, that retarded and senile groups can be expected to have deficiencies in a wide variety of cognitive functions, particularly those involving rate of performance. The relevance of data from these groups for the interpretation of cognitive functions in normal adult populations is open to question.

Data reported by Chiang and Atkinson (1976) pose questions that even now have not been resolved in further studies. Radically different correlations (though based on Ns of only 15) between ECT measures and SAT scores were obtained. Following are "significant" correlations (along with parallel, non-significant ones) from their study:

Measures Correlated	Males (N = 15)	Females (N = 15)
Average intercept (visual, memory); Memory span	-.543	-.022
Average slope (visual, memory); Memory span	.561	-.239
Average slope (visual, memory); SAT-V	-.365	.715
Average slope (visual, memory); Average SAT (V, M)	-.448	.646

The general magnitude of some of these correlations would appear to rule out the notion that visual and memory slopes are specifically related to speed components of the SAT. The sex differences in the correlations, which are generally significant, make any theoretical interpretation of the relationships difficult. The authors explore and reject several possible alternative explanations of them. One is tempted to dismiss the results as of no lasting significance, arising from a classic Type I error. (The several significant correlations cited above are not completely independent.) Unfortunately, no replication of the results has appeared in print, as far as we are aware.

Rose (1974) studied a number of cognitive tasks in relation to reported SAT scores of 50 males and 50 females; separate correlation matrices for the two groups are presented in an appendix to his report. Correlations between SAT and ECT variables are generally low and non-significant, and correlations do not differ in any marked way between sexes, with one surprising exception. On Day 1, the correlation between SAT and the A-B reasoning task scores (see p. 167) was .08 for males and .48 for females; on Day 2, when the A-B task was again administered, the values were -.04 and .62, and on Day 3, the values were .00 and .57. Inspection of the relevant means and S.D.s yields no suggestion for explaining this apparently consistent sex difference.

Other than in the studies just described, few investigators have looked at sex differences; often investigators do not even report the sex composition of their samples. In view of the possibility that sex differences are critical in relations between ECT and psychometric variables, one hesitates to pay much attention to studies that do not consider male-female differences. Hogaboam and Pellegrino (1978) found no relations between measures for a categorical decision task and SAT (see p. 163a); it is just possible that opposite-signed correlations for the two sexes balanced out to insignificance with pooling of these groups. Goldberg, Schwartz, and Stewart (1977) found no significant sex differences in mean RTs for their Posner-paradigm tasks, but reported no investigation of possible interactions between sex and verbal ability as measured by the Lorge-Thorndike Intelligence test. Kail and Siegel (1977) found striking sex differences in processing of verbal vs. spatial information in a memory task (see p. 217) but did not correlate these differences with any psychometric measure. Because their task was rather unique and novel it is difficult to relate their results to those of, say, Chiang and Atkinson.

Among results that argue for at least moderate relationships between general intellectual and verbal ability and ECT variables, even though sex differences were either not found or not investigated, are those of Keating and Bobbitt (1978) and Lansman (1978). Finding no significant sex interactions with other effects, Keating and Bobbitt reported significant relations for Raven matrix scores with slopes of Choice reaction time, memory scanning, and physical-name matches. Lansman found digit span and latency variables on sentence verification and three-term series problems to have significant correlations with verbal scores on the WPC test.

The net impression from many of the relevant studies is that slope parameters of ECT performances are more likely to have significant relationships with psychometric measures than intercept and simple reaction time parameters, but the relations are generally weak, and this observation must be qualified by pointing out the possibility of their being specific to speed components of the psychometric measures. This may be true even when the psychometric measure is such a generally accepted test of intelligence as the Raven matrix test, as in Keating and Bobbitt's study, or in Jensen's (1979) study. In our reanalysis of the latter study it appeared that Raven scores shared variance between an ability factor and a speed factor; Thissen (1979) showed that Raven scores may have both speed and power components.

In the studies surveyed here, ECT variables in the memory domain showed few significant relations with ability variables. Berger (1977) found practically zero relations between memory span variables and vocabulary. The SAT and similar verbal ability scores had low (though generally positive) correlations with the many memory task scores studied by Underwood, Boruch, and Malmi (1978); the relations were so small, in fact, that the verbal ability variables were not included in their factor analysis of the memory task scores.

It is difficult to assess the general significance of R. Sternberg's (1977) findings for "components" of analogical reasoning tasks as predictors of psychometric scores. Very probably one may conclude that the findings reflect significant and true relations (despite the very small Ns used in multiple regression analyses), but this may be only because the laboratory tasks are highly similar to the items in the psychometric measures. Much more research to generalize the validity of the reasoning task components beyond their counterparts in psychometric tests is needed.

A summary statement for this section has to be that the case for significant and interpretable relations between elementary cognitive "current information processing" tasks and conventional tests of general intellectual ability has much promise but does not yet have adequate support, mainly because there has been inadequate analysis of the components of conventional tests, but also because we do not yet know enough about the dimensions of ECTs. We are very far from being in the position of replacing conventional psychometric measures with batteries of ECTs.

Uses of ECTs in Prediction

Prediction of Scholastic Achievement

Although, as we have seen, scholastic aptitude tests have frequently been used as criteria against which to evaluate ECT performances, as far as we are aware ECT measures themselves have not been studied as predictors of scholastic achievement. It remains for researchers to investigate whether some set of ECT measures could be found to have validity in predicting academic performance, either by themselves or in conjunction with conventional psychometric tests. If the claims for ECTs as superior measures of basic cognitive functioning have any justification, as we believe they do, one could expect them at least to make a significant contribution to such prediction beyond that afforded by conventional tests.

Prediction of Training and On-Job Performance

Two studies have come to our attention that investigated correlations between ECT performance and training or on-job performance. (A study by Federico & Landis, 1979, of cognitive abilities in a computer-managed course in electricity and electronics will not be considered because the predictors were not what we regard as ECT measures, but more conventional tests of cognitive processing.)

Love (1977) used various measures of performance of students in a computer programming course as criteria for the predictive validity of three tasks that we would characterize as ECTs, namely, a continuous paired-associate learning test (CPAL) based on programming content, a digit-span task, and a free recall learning task from which clustering measures were derived. Guilford's Perceptual Speed test, a more conventional psychometric test, was also used, on the basis of previous experience with it as a successful predictor of programming ability. Results of the study are based on Ns between 29 and about 50. It was found difficult to develop reliable measures of programming performance, despite considerable effort, and these measures had little relation to course grades. Among the few significant predictive validity coefficients found in the study are the following for ECT measures and for the Perceptual Speed test (from Love's Table 6, p. 37):

Predictor	r	Criterion Measure
Perceptual Speed	.68	Number of program substitutions
Number correct, CPAL task	.57	Number of program substitutions
Perceptual Speed	.57	Total number of program changes
Digit Span	-.52	Maximum number of program runs
Percent correct, free recall	-.45	Number of logical program errors

Some of these results "make sense," while others are counterintuitive. Love remarks that there is "evidence for a relationship between programming performance and human information processing--albeit complex!" (p. 36). We can only comment that the results show some promise for the validity of ECT measures in this type of situation, but a greater variety of well-defined ECT dimensions should be explored in future research.

Cory (1977) reported on the relative utility of conventional vs. computerized testing with the Graphic and Interactive Processing (GRIP) battery (see p. 75) in the prediction of performance of naval enlisted personnel in four job classifications (Electrician's Mate, Personnelman, Sonar Technician, and an "undifferentiated apprenticeship"). The GRIP battery contains a number of measures that we would characterize as ECTs. Cory obtained validity coefficients of all measures against global ratings of job performance and against 12 rated job elements such as skill in writing, verbal communication, attention to detail, etc. Against global performance, impressive contributions to validity were made by certain tests in the GRIP battery only in the case of the Sonar Technician job ($\underline{N}$ = 37); this finding was interpreted by Cory as reflecting "the visual and perceptual requirements which have come to be associated with the ST job in recent years" (p. 561). The pattern of validity coefficients, examined from the standpoint of the factor structure for the test battery as a whole, suggests that the more predictive tests for this job were measures of factor CORB-E (see p. 125), Perceptual Closure, but the source of the validity of some tests seems to lie in specific variance. At the same time, a number of computerized tests had significant validities against specific elements common to the various jobs. Detailed study of these validity coefficients in the light of the factorial composition of the predictors, however, yields little suggestion of how specific dimensions of IDs are related to these job elements. Canonical correlation techniques might have produced more readily interpretable results. From the study as a whole, Cory concluded that computerized tests were frequently more useful than conventional tests.

From the limited data on possible predictive uses of ECT measures, one can only say that such measures have some promise as supplements to more conventional tests, but probably not as replacements for them. Better designed and more comprehensive sets of ECT measures should be used in further predictive studies against both training and job criteria.

Other Uses of ECT Measures

Cognitive Functioning in Relation to Physiological Condition

Uses of ECTs for assessing cognitive functioning under various conditions of physiological stress (diurnal variation, sleep loss, alcohol and drug use, anoxia, illness, etc.) have been briefly reviewed by Trumbo (1973) and Hunt (1979; see also Colquhoun, 1972). Trumbo proposes a series of prototype tasks of vigilance, reaction time, biphasic movement, tracking, and time-sharing. Hunt mentions a number of the ECTs we have focused on in the present review, pointing out that some of them can easily be converted to paper-and-pencil format, e.g. the Posner-paradigm task, the Clark and Chase sentence verification task, and the mental rotation task. He urges an inter-laboratory team approach to survey literature and conduct requisite research. Some of the ECTs studied by Rose (1974) were developed originally in the context of a project to investigate effects of high-altitude anoxia.

It is much beyond the scope of the present review to survey the fairly extensive literature that already exists concerning physiological effects on cognitive functioning. This review, however, should be of use in pinpointing dimensions of IDs that should be explored to find those that might be especially sensitive to changes in physiological condition. Indeed, information on physiological effects may be critical in the interpretation of ECT performance. For example, if physiological effects are prominent in reaction time performances, RT measurements taken in many ECTs might be of little use in assessing persisting IDs unless account is somehow taken of such effects.

Age Changes in ECT Performance

The present review has given little attention to the fact that many ECT performances change rather systematically as a function of age over the period from young adulthood, through middle age, up to old age and senility. (Developmental changes from infancy through adulthood were explicitly excluded from consideration.) Insofar as age effects are important, they must be taken account of in evaluating IDs in adult populations. It is beyond the scope of this review to consider these age effects, but the reader may be referred to the comprehensive treatments now available in several chapters in the Handbook of the Psychology of Aging edited by Birren and Schaie (1977). References to studies of ECT performance occur frequently in these chapters. In Chapter 1, Birren and Renner discuss general problems in evaluating and interpreting age changes in speed of response in reaction time and perceptual masking experiments. In Chapter 2, Schaie touches on the problem of whether psychometric and other instruments developed for children or young adults are suitable for use in studying performance of older persons (see also Baltes & Willis, 1979). It would appear, however, that this problem centers in instruments with specific verbal or knowledge content, like vocabulary and information tests, where fashions of usage or current interest may have changed over decades; it is not so likely to arise with most of the ECTs we have considered. Subsequent chapters in Birren and Schaie's handbook refer to data on various reaction time tasks (simple and choice reaction, stimulus matching, memory search, etc.) as useful indicators of age changes. For example, Marsh and Thompson (Chapter 11, p. 233) cite use of the Sternberg memory-search task in conjunction with studies of age changes in evoked potentials and other EEG phenomena. Craik (Chapter 17) reviews age changes in memory, citing data on digit span, free recall, and other ECTs; Arenberg and Robertson-Tchabo (Chapter 18) discuss effects of age on learning ability; and Welford (Chapter 19) gives a particularly enlightening review of reaction time and motor performance changes over age. Further information on certain types of ECTs that have been considered in the present review can be gleaned from chapters on visual and auditory perception, intellectual abilities, and problem-solving performances.

At the same time, it appears that gerontological research has focused on a relatively limited variety of cognitive tasks. Such research might profit from use of other tasks that have been described and analyzed here, and from some of the methodological recommendations that we have made.

Chapter 6

PSYCHOLOGICAL THEORY AND THE STUDY OF ECTs

Introduction

Several writers have urged closer connections between psychological theory and the study of individual differences, because of the promise of mutual benefits to the two fields. Hunt (1978) and Estes (1974) have centered their attention on the analysis of intellectual behavior in terms of possible theoretical explanations. Underwood (1975) has proposed that IDs could be a "crucible" in nomothetic theory construction, and perhaps he has most explicitly stated the "generalized case":

> If we include in our nomothetic theories a process or mechanism that can be measured reliably outside of the situation for which it is serving its theoretical purpose, we have an immediate test of the validity of the theoretical formulation, at least a test of this aspect of the formulation. The assumed theoretical process will necessarily have a tie with performance which reflects (in theory) the magnitude of the process. Individuals will vary in the amount of this characteristic or skill they "possess." A prediction concerning differences in the performance of the individuals must follow. A test of this prediction can yield two outcomes. If the correlation is substantial, the theory has a go-ahead signal, that and no more; the usual positive correlations across subjects on various skills and aptitudes allow no conclusion concerning the validity of the theory per se. If the relationship between the individual difference measurements and the performance is essentially zero, there is no alternative but to drop the line of theoretical thinking. (p. 130)

From Underwood's perspective, it would appear that ID research has more a negative than a positive role in psychological theorizing; it assists in rejecting wrong theories, but it does not aid in their confirmation. Underwood goes on to suggest three "guidelines" for linking IDs to theory:

> (1) The theory must assume at least two intervening processes, and these processes must interact in some way to relate the independent variables to the dependent variable.
>
> (2) . . . any assumed process must be tied to at least one independent variable.
>
> (3) . . . great latitude, perhaps along several different dimensions [must be allowed] in proposed intervening processes. (p. 131)

As one example of a context in which ID findings could be linked to progress in psychological theory, Underwood mentions his speculation that the superiority of spaced repetitions of words in free recall over massed repetitions might be due to a "reduced processing" of massed items, a speculation that (as we interpret Underwood's statement) could be disconfirmed if the superiority was found to be unrelated to subjects' "propensity to attenuate processing."

The present review, dealing with individual differences in the performance of what have been called ECTs (Elementary Cognitive Tasks), has disclosed many dimensions and features of those differences. No evidence of IDs in "propensity to attenuate processing" has come to our attention, but results of studies by Underwood and others in the domain of memory, as well as results in many other domains, may be pertinent to the concerns of Underwood and other psychological theorists. The dimensions and types of IDs that have been identified could undoubtedly have roles in the development of psychological theory along lines suggested by Underwood. It is believed, however, that their roles can be in positive as well as negative contexts, insofar as they represent psychological "facts" to be explained and interpreted in terms of their genesis, their consequences, and the factors that affect them.

In this chapter the dimensions of IDs that have been disclosed in this review cannot again be enumerated--that has already been done, briefly, in the preceding chapter. Nor can their implications for psychological theory be indicated in detail--that is a task for the psychological theorist, who will, it is believed, find much grist for his or her mill in these pages. One example of a finding that may challenge the theorist, however, may be given. In the exploration of the domain of "mental comparison" processes it appeared that IDs in visual search processes are highly correlated with IDs in memory search processes of the sort that are presumably tapped in the well-known "Sternberg paradigm." The implication of interest to the theorist, it would seem, may be that memory search processes are simply covert parallels of overt visual search processes.

Since it appears that the notion of psychological process would play a central role in the use of ID findings in psychological theory, some further attention is given in this chapter to the possible relations between ID dimensions and psychological processes, and to the methodology for studying these relations.

Finally, some thoughts on the possible use of ID research in the parameterization of psychological science are offered.

Cognitive Processes, Components, Factors, ECTs, and IDs

Throughout this review, it has been tacitly assumed that dimensions of IDs in cognitive processes are intimately associated with variance over individuals of measurements derived from ECTs. While this assumption is regarded as tenable in a broad sense, a satisfactorily precise model of the relationship between ID dimensions and ECT measurements needs to be formulated.

To aid in this formulation, we appeal to the notion of "component" that has been offered by R. Sternberg (1977) and further explicated by him (1979). At the same time, we want to propose what we believe is a more satisfactory delineation of the relation between components and factors (or "latent traits") than has been put forward by Sternberg.

Chapter 4 of Sternberg's monograph (1977) presents a quite detailed and elaborate system of what he terms componential analysis. It is an impressive contribution to the theory of information processing in relation to individual differences, and the experiments reported in the remainder of the monograph do much to give it support. While we agree with much of this system--certainly its spirit and intent, and a great deal of its content--we believe it contains certain imperfections and areas for needed improvements and refinements. The improvements are needed precisely in those portions of the theory that deal with relations between components and individual difference traits or dimensions.

Two chapters earlier, Sternberg deals with "the differential approach," including the factor-analytic approach. Since he contrasts componential analysis with factor analysis, makes a number of criticisms of it, and yet in many ways incorporates factor-analytic models and procedures into componential analysis, we feel it necessary, first of all, to make certain remarks to qualify Sternberg's statements about factor analysis.

It is necessary also because factor analysis deals in a very essential way with individual differences and latent traits in relation to manifest variables. Our conception of factor analysis as an approach to individual differences is somewhat different from Sternberg's (and perhaps different from that of many factor analysts).

One of Sternberg's criticisms of factor analysis is that it is "generally inter-individual--it analyzes patterns of individual differences across subjects." He continues:

> Since individual differences are meaningless in the context of one individual, it is not clear how factor analysis could enable us to discover what the components within an individual are. While certain modes of factor analysis could be used intraindividually, it has not been shown that they could discover underlying components of intelligence. (p. 33)

Exactly what Sternberg has in mind in saying that "certain modes of factor analysis could be used intraindividually" is not clear, but his recognition that factor analysis leaves the door open to intraindividual analysis is gratifying. In any case, let us note that the fundamental factor model equation is a model for the composition of an *individual's* score on a variable j. As Sternberg gives this equation (p. 16, Equation 2.10), it is as follows:

$$z_j = a_{j1}F_1 + a_{j2}F_2 + \ldots + a_{jn}F_n + d_jU_j \ ,$$

where z_j is a given subject's score on a variable j, the Fs are the individual's (standard) scores on factors 1 through n (the number of variables), U_j is the individual's score on a factor (including error) specific to variable j, and the a's and d_j are coefficients that state how the factors are to be weighted for the particular test j. We would prefer to modify this equation in two minor ways, however. First, let us more clearly indicate the application of the equation to a particular individual by using the subscript i to denote that individual. Second, let us assume, with no loss of generality, that the number of common factors is $m < n$. One of the purposes of factor analysis is to reduce the number of dimensions needed to describe test scores, and many of the developments of factor analysis have to do with the estimation of an optimal or satisfactory value of $m < n$. The number of common factors, m, is rarely larger than a third to a half of the number of tests, especially in well-designed factor batteries. For clarity and simplicity in exposition, let us assume that for a given set of data, m is exactly 3. We now have a modified equation:

$$z_{ji} = a_{j1}F_{1i} + a_{j2}F_{2i} + a_{j3}F_{3i} + d_jU_{ji} \, .$$

In principle, there is no reason why one could not add the subscript i to the coefficients a_{j1}, a_{j2}, a_{j3}, and d_j to give a_{j1i}, a_{j2i}, a_{j3i}, and d_{ji}, to indicate that the score description is specific to individual i. That is, one could allow the coefficients themselves to vary over individuals; the coefficients a_{j1}, ... a_{j3} determined by the usual procedures of factor analysis performed on separate *groups* of individuals will in general yield different values of the coefficients for the separate groups. While variation of values is ordinarily thought of as arising solely from sampling, the variation could also arise from genuine differences among samples. Suppose, for example, that two groups are selected on the basis of the strategy their members adopt in performing the task that gives rise to the variable, and it is found that the coefficient a_{j3} is substantially positive in one group and zero in the second group (after any appropriate rotation of axes, a matter we discuss below). This could be interpreted as showing that members of the first group draw on their ability in factor 3 in order to perform the task, while members of the second group do not. If groups can differ in this way (as ordinary methods of factor analysis could reveal), so also can individuals, as members of groups. The only difficulty is that conventional methods of factor analysis cannot estimate separate coefficients for each individual, simply because normal data sets do not provide enough degrees of freedom for the estimations. Data with repeated measurements on individuals might be treated to yield such estimates, if stable estimates of factor scores could be obtained, independent of the data on repeated task measurements.

Let us note, at this point, that the score z_{ji} can be, in principle, *any* kind of score derived from performance on a task. It could be, for example, a "component score," in Sternberg's terminology, derived by his componential analysis procedure (as explained above, pp. 225-233), and a series of scores z_{1i}, z_{2i}, ..., z_{ci}, ..., z_{ki} (c = 1, k) could be the k component scores derived by componential analysis for individual i from that individual's performance on a set of related tasks. Each score z_{ci} might then be described by a factor equation with a different set of coefficients a_{c1i}, a_{c2i}, a_{c3i}, and d_{ci}, although one might hope that over a sample of individuals the coefficients would be simply a_{ci}, a_{c2}, a_{c3}, and d_c representing genuine population values uniformly meaningful over the individuals. (Note that we are replacing the subscript j with c to indicate that the variables are component scores.) We have established, in any case, that the fundamental factor equation pertains essentially to one individual at a time, and thus, that there is nothing in the basic model to exclude the possibility that factor analysis could deal with intraindividual data. We will come back to this point later.

A second criticism that Sternberg levels against factor analysis is one commonly made, namely that factor rotation is indeterminate: ". . . while the factor space is unique, the orientation of axes is not. The axes may be rotated in an infinite number of ways, each of which define factors along different dimensions. The different dimensions have different psychological implications" (p. 31). He continues by citing Guilford's opinions on factor rotation, Guilford's support of subjective (including Procrustean) rotations, and Horn and Knapp's (1973) doubts about such methods, ending by noting:

> What is particularly disconcerting about the theoretical status of the psychometrically derived and tested theories of intelligence is that a major differentia among them (if not *the* major differentia) is the type of rotation used upon the initial factor matrix. Since all rotations of a given number of factors extracted from a particular set of data account for identical proportions of variance in the data, it is clear that methods other than factor analysis will have to be used to choose among alternative theories. (p. 32)

In Sternberg's original exposition of problems of rotation in factor analysis, he distinguishes between "objective" methods and "subjective" methods as follows:

> An *objective rotation* is one in which all investigators who use the method on

> the same data will arrive at the same result, regardless of differing a priori hypotheses they may have had regarding the outcome. A subjective rotation is one in which investigators with different hypotheses may get different results from the same set of data. In subjective methods, investigators usually specify a target matrix that represents hypotheses about the configurations of factor loadings after rotation. The [Procrustean] rotation is then performed so as to minimize the discrepancy of the solution from the target matrix. (p. 20)

The distinction made here puts undue emphasis on the role of factor hypotheses in the process of rotation. In actuality, it is not necessary to use hypotheses at all in performing "subjective" rotations, and such rotations need not be Procrustean. Although Sternberg seems to recognize that the purpose of "objective" rotation is to achieve, as far as possible, the criteria of simple structure advanced by Thurstone (1947) and thus to eliminate the role of any specific factor hypotheses in rotation, he fails to appreciate, or at least to convey in his exposition, the psychological import of simple structure criteria.

At the same time, Sternberg fails to recognize adequately the role of a very general kind of hypothesis, embodied in simple structure criteria, about the preferred magnitudes and signs of coefficients in the fundamental factor equation. Simple structure criteria include the requirement that as far as possible the coefficients $\underline{a}_{\underline{j}1}$, $\underline{a}_{\underline{j}2}$, ... for any variable $\underline{j}$ should be zeroes or near zero, leaving one (or a small number of them) to be positive (not negative). This requirement embodies the principle of positive manifold, which depends on the orientation of the variables in a positive direction such that high values represent correct or accurate responses, as opposed to errors, or rapid responses (if they may be considered desirable) as opposed to slow responses.

To illustrate, suppose that we have two variables, one being a speed component measured in msec, the other being an accuracy component measured in terms of the probability of a correct response. Suppose that these variables, in their raw form, have an intercorrelation, over a sample of subjects, of -.30. That is, the faster responders tend to be somewhat more accurate. Suppose further that these two variables are embedded in a data set such that three factors are needed to account for the common factor variance. In analyzing the data, we would first reflect the speed component variable, with the result that its correlation with the accuracy component is positive, +.30. In a principal factor solution for the total data set, the coefficients $\underline{a}_{\underline{j}1}$, $\underline{a}_{\underline{j}2}$, $\underline{a}_{\underline{j}3}$ of the two variables on the common factors are found as follows:

	F_1	F_2	F_3
1	.352	.438	.731
2	.684	-.519	.391

Note that summation of the products of row-wise-paired coefficients reproduces the obtained correlation, .300. The principle of parsimony alone would lead us to reject this solution, since it suggests that both variables are related strongly to all three factors, and that they are "complex" in their factorial composition. Since the axes for the coefficients may indeed be rotated in an infinity of ways, there is an infinity of factor solutions like the above that could be rejected on grounds of lack of parsimony. One general hypothesis underlying simple structure is that variables are usually "simple" in their factorial composition, that is, that only one or a small number of latent traits are needed to explain their variance. (A latent trait that has a zero or near-zero ["vanishing"] coefficient for the variable would not be needed to explain variance.) In the construction of tasks or tests, or in the selection of variables to be submitted to factor analysis, one tries to form them so that they will reflect only one or a small number of hypothesized latent traits. If a variable turns out to have a complex factor composition in one analysis, one may try to construct new tasks or variables that will better distinguish the separate traits in a further study.

There is another ground for rejecting the solution shown above, that is, for not letting it stand without rotation. Variable 2, we note, has a high negative loading on Factor 2. This would mean that a person with a high score on factor 2 would somehow be disadvantaged in getting a high score on variable 2. The principle of positive manifold aims to act against finding this type of result. It represents the psychological hypothesis that a latent ability always acts positively, if it acts at all, in influencing positively oriented manifest variables. Consequently it specifies that factor coefficients should be either (1) positive (preferably, significantly so) or (2) zero or vanishing. The principle of positive manifold, however, does not establish any absolute prohibition against significant negative loadings. There are certain conditions where the structure of the data can force one to rotate, following simple structure principles, in such a way as to produce negative manifolds containing one or more significant negative loadings. (Such a circumstance is illustrated below, p. 277.) The most obvious case is where two positively oriented variables have a significant negative intercorrelation (a rare occurrence in the ability domain). Data exhibiting negative manifold should strongly impel one to form and test hypotheses about why a latent trait should tend to act negatively against high scoring on a variable.

Thus, the principles of simple structure, and the general psychological hypotheses underlying them, would dictate some rotation of axes for the above coefficients to positions that would eliminate the high negative loading and yield as many near zero coefficients as possible. But how decide on the appropriate rotations? One option is to use some "objective" rotation, such as Kaiser's (1958) Varimax procedure, that will on the average tend to satisfy simple structure principles. (Kaiser's procedure is better called an analytical procedure rather than an objective one; in any case, it will not always satisfy simple structure principles adequately. Indeed, there are circumstances in which it can produce highly misleading results.) Another option, not mentioned by Sternberg, is subjective graphical rotation to simple structure. Graphical rotation can be performed either with strict preservation of orthogonality or with rotation to oblique axes when the structure so demands. Our own preference is to start with a Varimax rotation and proceed to adjust it, usually obliquely, if the structure demands further rotation. Oblique rotation permits greater freedom in performing rotations, and it usually gives faster convergence; a final adjustment to orthogonality can be made if desired. Graphical rotation is perhaps more an art than a science; yet, in the early years of Thurstone's research laboratory experiments with "blind" rotations of the same data set independently made by two or more researchers showed high agreement between solutions. (From this standpoint, graphical rotation might be called an "objective" method, by Sternberg's criterion, because the investigators would arrive at approximately the same result, quite independently of any specific hypotheses they might have held. Actually, they could not have depended on any such specific hypotheses, because their "blind" rotations were conducted without knowledge of the identities of the variables.) The major principle followed in graphical rotation is to try to "tighten" the loadings around what Thurstone called "bounding hyperplanes," i.e., planes in higher order space that are defined by groups of test vectors that through axis rotations are made to have vanishing loadings on reference vectors perpendicular to these planes. The rotations are done by moving the reference axes of pair-wise factor plots. With a well-designed factor study, the bounding hyperplanes often appear with great clarity, giving one confidence in the validity of notions of parsimony and simple structure. Often, these structures replicate well over studies, provided the studies are well designed to test hypotheses.

In the light of all this, we have to take exception to the generally negative evaluation of factor analysis given by Sternberg on account of its supposed indeterminacy. Factor analysis is scarcely indeterminate if simple structure principles are observed in rotation. In the case of the hypothetical data given above, it is possible to rotate to the following simple structure:

	A	B	C
1	.600	.700	.000
2	.500	.000	.800

We have relabeled the factors as A, B, and C, for they are completely different from the factors we started with. The (orthogonal) transformation matrix is as follows, for any reader who wants to check:

	A	B	C
F_1	.917	-.283	.283
F_2	.367	.311	-.877
F_3	.160	.908	.389

After rotation, both variables are "complex," to be sure, since each has strong loadings on two factors, but there are no longer negative loadings, and zero loadings appear. In practice, the rotations would be based on a total data set, and the locations of the reference axes would be determined by hyperplanes with large numbers of vanishing loadings. All factors would have many vanishing loadings, and most variables would have one or two vanishing loadings.

The "bounding hyperplane" concept that lies at the heart of simple structure can be thought of as reflecting the idea that one wants to find striking contrasts between variables that do depend on a given latent trait and variables that do not depend on it at all. In the design of a set of variables to be submitted to factor analysis study, it is more important to select variables that are not expected to measure a hypothesized factor than to select variables that are expected to do so. Hypotheses about factor structure have a place--an important one--in the design of factor analysis studies; they need have no place at all in the process of rotation.

Perhaps, however, Sternberg recognized the role of simple structure in rotation (indeed, he uses Varimax procedures in "external validation" of componential analysis) and was concerned instead with the apparent conflict between such factor models as Holzinger's bi-factor theory, Thurstone's multiple-factor theory, Guilford's Structure-of-Intellect (SI) theory, and the Burt-Vernon-Cattell-Horn hierarchical models. In many respects there is little conflict among these models. As applied to the same set of data, all these models will produce approximately the same solutions, or solutions that are interconvertible by simple transformations. All observe at least some of the principles of parsimony and simple structure. The major difference among them is now seen to have to do with the treatment of what is regarded as "higher-order" covariance in the Thurstonean system, i.e., correlations between "primary" factors. This is almost a matter of taste, not theory. Some authorities prefer to look at a series of completely orthogonal factors, even though their number may be greater than the number of factors initially required to account for the variance of a data set, thus violating the principle of parsimony. Others are willing to think of factors in different orders of spaces. Still others (e.g. Guilford) are content to leave correlated variance in primary factor space, thus making minor violations of simple structure criteria. Since solutions are generally interconvertible (e.g., by the Schmid-Leiman [1957] orthogonalization) it is difficult to see that truly alternative or incompatible theories are involved. If "factors" are conceived of simply as sources of variance, it matters little whether a source of variance is identified in primary factor space or some other space For example, a "general" factor can be regarded as existing either in a second-order factor, in a separate orthogonal factor, or as embedded in two or more primary factors. Perhaps we are oversimplifying the problem of the relation between factor analysis and theories of intelligence, but it would require much more space to deal with it adequately and in depth, and we do not consider it worthwhile to do this here, in any case.

A third criticism of factor analysis made by Sternberg is that it cannot discover processes, and thus that it cannot discover components as Sternberg defines and "discovers" them. This should be taken not as a criticism but as a remark or comment, and it is one with which we agree. Factor analysis is not designed to discover processes (although many of its practitioners may have had, or still harbor, hopes in that direction); it can discover only sources of variance in behavior or other measurements. Some sources of variance may reside in processes, and factor-analytic results can be considered with that possibility in mind. But other sources of variance can reside, for example, in differences in knowledge or in practiced skill. Factor-analytic results can do no more than to suggest, in appropriate contexts, what latent traits of individual differences are sources of variance in the execution of processes.

This possibility may be illustrated if we now turn to a consideration of Sternberg's "components" and "component scores." According to him, "A component is an elementary information process that operates upon internal representations of objects or symbols" (p. 65). Later, he develops the notion of a component score as a parameter estimate for individual subjects. "[Component scores] are hypothesized to measure the durations or difficulties of the components of the information-processing model of task solution . . .

The component scores are viewed as measuring latent traits, the root processes underlying intelligent behavior" (p. 75). However, "the scores differ in the purity of the measured behavior."

Component scores may be viewed as ways of scoring performance on an ECT. This suggests to us the possibility of entering component scores as variables in a factor analysis in order to investigate sources of individual differences in them. Sternberg presents data on component scores and reference ability measures for the sample of 16 subjects involved in the People Piece and Verbal Analogy experiments; these data (Tables 7.10, 7.13, 7.18, 8.6, 8.7, and 8.10) are sufficient to enable us at least to illustrate the use of factor analysis with sets of component scores and reference abilities, despite the smallness of the sample. Such a factor analysis would seem to be in line with Sternberg's suggestion that "correlating component scores with reference abilities forces the investigator to show that identified components are of general interest, that they are correlated with variables other than themselves" (p. 92).

A graphically rotated orthogonal solution for the five component scores in the two experiments and seven reference ability scores is given in Table 7. (Unfortunately, Sternberg did not give sufficient data for the vocabulary test for it to be included in the analysis.) The results, incidentally, exhibit negative manifold, because even though all component scores were reflected it would be impossible to orthogonally rotate axes to eliminate some strong negative loadings. Five factors emerged by the unity-eigenvalue criterion, and these seemed sufficient; they accounted for 81.8% of the variance. Three of the factors, C, D, and E, were defined mainly by component scores for Application, Inference, and Mapping, respectively. These parameters are thus seen to show considerable generalizability over the two experiments. They were not represented in reference ability measurements, however. Possibly in future research one could identify reference ability measurements for them. The other two factors, A and B, were defined principally by reference ability tests for Reasoning and Perceptual Speed, respectively, but the parameters for Encoding, and Preparation and Response, were associated with them in a rather complex way. The parameter for

TABLE 7

Graphically-Rotated Orthogonal Factor Matrix for Components and Reference Ability Tests in Sternberg's (1977) People Piece and Verbal Analogy Experiments

		Factor					
		A	B	C	D	E	h^2
People Piece Experiment (Components)							
-a (Encoding)	1	-.59	.42	-.07	.24	.02	.58
-x (Inference)	2	.02	.02	-.14	.23	.75	.64
-y' (Mapping)	3	.00	.07	-.18	.81	-.02	.70
-z' (Application)	4	.00	.06	.62	.41	-.41	.72
-c (Preparation & Response)	5	.77	-.12	.28	.35	-.04	.81
Verbal Analogy Experiment (Components)							
-a (Encoding)	6	-.61	-.01	.55	-.31	.18	.81
-x (Inference)	7	.24	.13	-.47	.62	.29	.77
-y' (Mapping)	8	.20	-.18	.29	.69	.04	.63
-z' (Application)	9	-.02	.13	.85	.04	-.05	.74
-c (Preparation & Response)	10	.75	-.10	.26	.33	.00	.75
Reference Ability Tests (Scores)							
Word Grouping	11	.64	.05	-.08	.47	-.06	.64
Letter Series	12	.74	.16	.16	.34	.06	.72
Cattell Reasoning	13	.73	.30	.10	.31	.15	.74
Same-Different	14	-.12	.86	.05	.05	-.04	.76
Letter Identification	15	.05	.96	-.04	.17	-.15	.98
French Number Comparisons	16	-.10	.64	.29	-.07	.37	.64
French Identical Pictures	17	.28	.72	.36	.00	.24	.79

Preparation and Response is most clearly associated with factor A, Reasoning: People who are quick in "preparation and response" tend to make high scores on reasoning tests, even though (as we are assured by Sternberg) the reasoning tests are not excessively speeded, if at all. At the same time, high scores on factor A are associated with slow encoding in both experiments. In the case of factor B, high scores in Perceptual Speed are seen to be associated with fast encoding, but only in the case of the People Piece experiment. There are various other complexities illustrated in the factor loadings. For example, fast Encoding is associated with fast Application in the Verbal Analogies experiment, but with Mapping in the People Piece experiment. Fast Inference is associated with fast Mapping and slow Application in the Verbal Analogies experiment.

These results shed some light on the nature of component scores and tend to support Sternberg's view that they differ in the purity with which they measure latent traits. Factor analysis can show how source traits of IDs, particularly when represented by reference ability tests, can enter into measurements of processes. A given source trait can enter into the determination of two or more component processes, and a given component process can sometimes be affected by two or more source traits of IDs. The extent of such determinations can be affected by the nature of the task from which the component scores are derived. For example, Encoding speed was associated with Perceptual speed in the People Piece experiment but not in the Verbal Analogy experiment, possibly because of the use of pictorial stimuli in the former, in contrast to printed words in the latter.

The major points of this section may be summarized as follows:

1. Components are seen as processes that can be identified and often generalized over tasks, but they may operate somewhat differently in different tasks, depending on the nature of those tasks.

2. Component scores are ways of scoring performance on ECTs; they are measures of the duration and operational accuracy of component processes in a given type of task.

3. Component scores are not, however, direct measures of source latent traits of individual differences. Instead, they may reflect the operation or influence of such source traits.

4. To investigate the factorial composition of component scores, i.e., the source traits of IDs, singly or in combination, that contribute to their variance over individuals, component scores for a given task may be entered into a factor analysis, along with component scores for other tasks and scores on appropriate reference ability tests. The selection of tasks and reference ability tests can reflect hypotheses as to the nature of the source traits.

5. Factor analysis is an appropriate and sufficiently objective method for making such investigations. The actual machinery of factor analysis is not dependent on any hypotheses adopted in advance of the analysis; it affords a way of testing those hypotheses.

6. Since fundamental factor equations can apply to one individual at a time, factor analysis can be used on an "intraindividual" basis. The possibility of obtaining meaningfully different factor solutions for different groups or individuals (e.g., using different strategies of task performance) is suggested.

IDs, ECTs, and Parametric Approaches in Psychology

In the "hard" sciences, one can have a Handbook of Physics and Chemistry that gives detailed and well-established information on the properties of chemical elements and compounds, and many other matters of use to researchers and practitioners, all unified within a system of measurement of time, distance, mass, etc., based on properties of matter and energy. Even in biological and medical sciences it is possible to list parameters of growth and physiological processes, often using the same metric system (the Système Internationale adopted by treaty among nations) developed in physical science. Aside from certain compendia of human physical and behavior facts that have been assembled for human engineering (Morgan, Cook, Chapanis, & Lund, 1963; Parker & West, 1973), no such handbooks of metricized scientific facts and data are available in experimental psychology. The psychological literature mentions numerous scientific laws, e.g. Hick's law (Hick, 1952) or Fitts' law (Fitts, 1954; see also Welford, 1977, p. 454), but many of the parameters of such laws are arbitrary constants not readily specifiable in anything like the Système Internationale.

One probable reason for this lack is that many of the free parameters of psychological laws are related to individual differences. Up to the present, it has rarely

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been possible to express parameters of individual differences in absolute measurements or in terms of event probabilities that could be dealt with in appropriate nomothetic and mathematical networks. IDs have usually been measured on an arbitrary, relativistic, or "norm-referenced" basis. Performances on psychological tests, such as the SAT and many others, are expressed initially in terms of test-centered "raw score" scales and then in terms of various derived scales such as the IQ and the "standard score," both of which are derived from normative information.

Measures of ECT performance, on the other hand, offer the possibility of bringing IDs into the realm of absolute measurement and the Systême Internationale. Latency measurements are normally expressed in msec or sec, while accuracy measures can be expressed in proportions or probabilities. The "components" of Sternberg's system of componential analysis are similarly treatable as times or probabilities. The conditions under which an experiment or measurement is conducted are generally expressible, in large part, in terms of physical units, frequencies, or probabilities, and stimuli can often be described in this way. Many attributes of words, for example, can be expressed in terms of frequencies and probabilities.

In this perspective, it should be possible to express parameters of IDs as measurements in a physical and real number system. For many years, digit span performance has been expressed in terms of such a system (of course, under certain psychophysical assumptions concerning thresholds and gradients), but the same or similar logic could be applied to measurements of performance in many other ECTs. What would be needed, in many cases, would be further attention to the nomothetic measurement of experimental conditions, stimuli, and performance relationships. For example, it should be possible to extend or refine the methods proposed by Carroll and Burke (1965) for parameterizing paired-associate learning performance in the light of individual differences. ID parameters might also be developed for description of performance in Shepard and Teghtsoonian's (1961) running recognition tasks, using their equation and also considering the characteristics of the stimuli and conditions of the task.

Research and development along such lines, together with further development in latent trait theory (Lord & Novick, 1968) should make it possible, eventually, almost entirely to dispense with normative procedures of measurement, and to move experimental cognitive psychology closer to the status of a true science. Incidentally, it may be pointed out that absolute or quasi-absolute parameters are required for full application of the writer's "model of school learning" (Carroll, 1962) which assumes that amount and rate of learning are a function of several situational and ID factors that can be expressed in part in terms of physical measurements of time.

Chapter 7

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This monograph is essentially an expansion, by a large factor, of a small portion of a review by Carroll and Maxwell (1979) of recent research in human cognitive abilities that was published in the Annual Review of Psychology. It focuses on individual differences (IDs) found in performance of what are called Elementary Cognitive Tasks (ECTs); see a definition of this phrase in Chapter 2. Since it concentrates on findings from recent studies it makes no claims to being a complete or exhaustive summary of the totality of research literature on the area covered.

In Chapter 1, questions that the survey would attempt to consider were listed. These questions will be listed again here, with tentative answers and references to fuller discussions of them in the main body of the text.

1. What kinds of IDs are observable in simple cognitive tasks?

Two approaches were employed to answer this question. After a mainly theoretical chapter (Chapter 2) that developed a scheme for organizing the material surveyed, results of correlational and factor-analytic studies were analyzed or re-analyzed to attempt to disclose the dimensions of IDs that could be identified in performance on a variety of ECTs that have been studied in recent literature in experimental cognitive psychology. Chapter 3 presents the findings of this survey from the standpoint of factor analysis; a brief summary is to be found on pp. 243-253. The second general approach was task analysis; the varieties of ECTs that have been studied were classified and discussed in depth in Chapter 4.

A large variety of ID dimensions were identified. The majority of these pertained to measurements of speed of performance or response; dimensions pertaining to accuracy or correctness of performance were much less emphasized, except in the memory domain. While many different dimensions were identified (perhaps up to 25 or 30), it was difficult to cross-identify the factors and dimensions. It is probable that further research could substantially reduce the number that can be firmly established, mainly by showing that pairs or groups of dimensions now indicated only as possibly distinct are in fact not distinct.

2. Are these IDs of sufficient extent, and can they be made to attain sufficient reliability, to lead one to believe that they reflect stable characteristics of individuals, and to suppose that they might be relevant in personnel selection and training programs in an organization like the U.S. Navy?

The fact that high internal or test-retest reliabilities have been observed for many of these ID dimensions suggests that they do indeed exhibit sufficient variance and stability in normal adult populations to make them of potential relevance in personnel selection and training programs, and in other contexts.

3. How can these IDs best be observed? Under what conditions, and through what procedures, can they best be measured? How should performances be scored and otherwise reduced to quantitative terms? Are the IDs reflected better in gross speed and accuracy scores, or are they better reflected in carefully defined parameters of task performance in relation to information processing theories? Are "componential analysis" procedures (as suggested by Sternberg, 1977) to be recommended in obtaining suitable performance measures, and if so, how generally can such procedures be applied?

These questions are considered in considerable detail in Chapters 2, 3, and 4, where numerous recommendations are made regarding the observation and measurement of IDs in specific ECTs. Accuracy of measurement depends in part on the experimental procedures employed, and in part on methods of observation and scoring. For practical purposes it is frequently possible to obtain measurements in terms of gross speed and accuracy scores, but for more refined measurements, and certainly in research, carefully defined parameters should be employed. Sternberg's componential analysis procedures are believed to have considerable promise and can be more generally applied, in conjunction with factor analysis and latent trait theory, than has been the case until now.

4. From a factor analytic viewpoint, what are the dimensions of IDs in simple cognitive tasks? How general are these dimensions over a wide variety of such tasks, or is it the case that IDs are largely specific to narrowly defined classes of tasks?

Fairly large numbers of ID dimensions identified here are at present known only as associated with rather narrowly defined classes of tasks. Presently available data, however, do not exclude the possibility that these dimensions can eventually be shown to have much greater generality over different classes of tasks. Research has not yet been sufficiently extensive to reveal any major amount of hierarchical structure among the various ID dimensions that have been disclosed.

5. To what extent do IDs measured through simple cognitive tasks relate to dimensions of IDs as measured by more conventional psychometric tests? To what extent, if at all, are these IDs involved in the performance of more conventional tests, and if so, can conventional tests be adapted so as to better reflect the functioning of such IDs? If there are significant relationships between IDs measured through simple cognitive tasks and those measured through more conventional tests, do these relationships reflect intrinsic common elements between the two classes of variables, or do they reflect the operation of extrinsic, "third variables"?

Analysis of data in the literature reveals many instances in which dimensions of IDs in ECTs are associated with, or are highly similar to, dimensions identified in more conventional psychometric tests. At the same time certain of these dimensions may be novel and outside the normal realm of what can be readily measured by conventional tests. Many of the ECT ID dimensions can be easily measured in paper-and-pencil formats, although many precautions and safeguards would have to be instituted to prevent the operation of extraneous factors in such adaptations. Other ECT dimensions, however, can be measured only by computerized testing, often requiring specialized apparatus.

Examination of the literature suggests many ways in which conventional tests could be adapted to provide better measurement of basic aptitudes and capacities. Of particular interest would be improved methods of administering conventional tests to distinguish speed and accuracy (correctness) dimensions of ability.

There is as yet little firm evidence concerning ways in which ECT measurements relate to variance on conventional tests of intelligence and verbal ability. What relationships are revealed are weak, at least in normal adult populations; they are typically on the order of a correlation coefficient of .30 (i.e., 9% variance in common). There is little promise, as yet, of replacing conventional tests with batteries of ECT measurements. Some evidence suggests, however, that such measurements may be valuable supplements to conventional tests.

6. To what extent are IDs measured through simple cognitive tasks subject to the effects of specific education, training, practice, and other variables that would tend to reduce their suitability for use in personnel assessment and training programs? To

what extent do they vary as a function of such demographic variables as sex, age, SES, race, and occupation? To what extent do they vary as a function of strategies of performance that may be more or less arbitrarily chosen or adopted by examinees?

Since most of the data surveyed here have been collected on fairly homogeneous and specialized samples on a one-time or short-term basis, insufficient evidence has accumulated to answer these questions with any assurance. Most tasks are sufficiently novel to the average subject to yield high reliabilities without much practice; a few appear to require considerable practice, on the part of the subject, before they attain sufficient reliability and appropriate construct validity. Relatively few instances of important strategy differences in performance have been reported thus far, but the available evidence is sufficiently striking to suggest that the problem of strategy differences requires thorough examination.

7. To what extent, and in what way, is the study of IDs in simple cognitive tasks likely to lead to better understanding of human behavior, or to the development of psychological theory? What is the "construct validity" of these IDs, i.e., what do they "really" measure or reflect?

The net impression is that further study of IDs in simple cognitive tasks can be of great value in the development of psychology as a science. The construct validity of measurements of these IDs can be elucidated only through systematic and well organized research.

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APPENDIX

Factor Analyses of Data Sets

Explanatory Notes

1. Reference may be made to Table 2 (pp. 85-86), using the 4-letter designations assigned to each data set, for further information about sources, samples, factor analysis procedures, etc.

2. For some of the data sets, factor analysis was applied to only a subset of the variables given in the source. Variables that have been sign-reflected from variables in the original data sets are indicated by a minus sign (-) preceding the variable number. Where variables were not numbered in the source, variable numbers were created by numbering the variables in correlation matrices.

3. The general principle followed in arranging the tables is to assign each variable to the factor on which it has its highest loading (in absolute magnitude). Within a factor, variables are generally arranged in decreasing order of these loadings.

4. Values of $\underline{h}^2$ (communalities) are taken from the principal factor solutions on which each analysis is based, with the number of factors used in the analysis. In the case of orthogonal rotations, the value of $\underline{h}^2$ should be equal to the sum of the squares of the loadings, within rounding error. Most values in these tables are rounded to 2 decimal places from values with 5-decimal accuracy given on computer print-outs.

5. PC (principal component) and PF (Principal factor) eigenvalues are taken from the respective solutions, when available. For convenience, they are listed, in order, under columns designating rotated factors, but they are not to be taken as being associated with those rotated factors since rotations redistribute variance.

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Analysis ALRK (Allen, Rose, & Kramer, 1978)

Loadings on Oblique Axes

		Factor													
		A		B		C		D		E		F		h^2	
	Day r	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Factor A: Speed of Mental Comparison (?)															
Physical Match	-9,-10	.78	.67	.06	.09	.08	.01	-.11	.05	.09	.09	.09	.02	.72	.94
Set Membership,Int.	36,38	.78	.76	.03	-.05	-.05	-.09	-.03	.05	-.04	-.10	.41	.52	.73	.78
Ltr. Rotation,Slope	2,4	.54	.25	-.10	-.14	-.03	.09	.46	-.04	-.03	-.03	.06	.10	.56	.14
Factor B: Memory Span, Registration (?)															
Letter recall,Slope	-14	.02	-.06	.92	.97	-.01	-.01	-.08	-.23	-.10	-.06	.04	-.01	1.00	1.00
" " ,Intercept	13	.00	.04	.72	.74	.03	-.02	.13	.09	.11	.16	-.08	.01	.73	.74
Factor C: Perceptual Speed (?)															
Scan & Search, Slope	-47	-.30	.17	.01	-.02	.83	.83	-.08	-.09	.08	-.03	.11	-.05	.93	.74
" " " , Intercept	46	.31	-.21	.00	.00	.83	.77	.04	.01	-.09	.15	-.06	.07	.97	.93
Factor D: Free Recall (Secondary Memory) (?)															
Sent.Recall, Max Cluster	58	-.04	.02	-.01	-.14	-.02	-.05	.53	.57	.12	.17	-.16	-.13	.30	.36
Sent.Recog,Mean Error	-52	.06	.10	.14	.01	-.06	-.08	.49	.41	.09	.18	-.01	.07	.27	.20
Ltr.Rotation,Intercept	-1,-3	-.10	-.18	-.01	-.06	.00	-.11	.53	.21	.07	.32	.21	.12	.51	.27
Factor E: Numerical Ability (?)															
Ment.Addit'n,Overall Mean	31	.05	.06	-.06	.00	.08	.15	.37	.48	.83	.73	-.09	-.02	.90	.71
" " ,Slope	28	-.01	-.04	.06	.12	-.14	.04	.10	.24	.50	.55	.18	.01	.44	.44
Factor F: Slope of Visual/Memory Search (?)															
Set Mem'ship,Slope	-37,-39	.07	.05	.01	.11	.16	.11	.16	.20	.01	-.15	.52	.75	.49	.83
Sent.Recall,Cluster Level	-59	.20	.18	-.07	.10	-.06	-.03	-.19	-.20	.12	.24	.51	.59	.31	.58

Factor Correlations

A	1.00	1.00	-.06	-.03	.13	.20	-.13	-.19	-.15	-.15	-.17	-.24
B	-.06	-.03	1.00	1.00	-.10	-.04	-.17	.19	.41	.18	-.01	.05
C	.13	.20	-.10	-.04	1.00	1.00	.16	.22	.09	-.12	.26	.19
D	-.13	-.19	-.17	.19	.16	.22	1.00	1.00	-.12	-.34	.30	.09
E	-.15	-.15	.41	.18	.09	-.12	-.12	-.34	1.00	1.00	.14	.13
F	-.17	-.24	-.01	.05	.26	.19	.30	.09	.14	.13	1.00	1.00

PC Eigenvalues	2.69	2.74	2.52	2.39	1.98	1.77	1.49	1.36	1.20	1.24	.91	1.01
PF Eigenvalues	2.42	2.41	2.24	2.16	1.71	1.59	1.20	1.03	.70	.85	.60	.62

Loadings on Oblique Axes produced by a Procrustes rotation using as a target matrix the average of "significant" loadings yielded by independent "blind" rotations of the respective data sets.

Analysis BRGR (Berger, 1977)

Loadings on Oblique Axes

Factor

		A	B	C	h^2
Factor A: Interference Resistance					
Delayed Digit Span 2-9	3	.83	.20	-.06	.78
Embedded Figures Test	9	.77	.17	-.09	.65
Rod and Frame Test	8	.77	.00	-.03	.62
Long Digit Span	1	.75	.25	-.04	.69
Retroactive Inhibition	2	.72	.30	.06	.74
Delayed Digit Span 4-7	6	.66	.02	.41	.86
Factor B: Registration					
Immediate Digit Span 2-9	7	.15	.76	.00	.67
Immediate Digit Span 4-7	4	.01	.67	.30	.70
Factor C: Proactive Inhibition					
Proactive Inhibition	5	-.02	-.01	.59	.39

Factor Correlations

	A	B	C
A	1.00	.08	.28
B	.08	1.00	.27
C	.28	.27	1.00

	A	B	C
PC Eigenvalues	4.78	1.46	.96
PF Eigenvalues	4.51	1.11	.49

Analysis CHAT (Chiang & Atkinson, 1976)

Loadings on Oblique Axes

Factor .

		A	B	C	D	h^2
Factor A: Speed of Mental Comparison						
VINT (Visual Search, Int.	3	.98	-.13	-.03	.31	1.06
MINT (Memory Search, Int.	1	.98	.28	.05	-.18	1.09
Factor B: Slope of Visual/Memory Search						
VSLOPE (Vis.Search,Slope)	4	.00	.99	.07	-.07	1.01
MSLOPE (Mem.Search,Slope)	2	.00	.87	-.07	.09	.80
Factor C: Memory Span						
-MTOT (Memory Span)	-5	-.03	-.04	.88	.03	.81
-MSPAN (Largest Mem. Span)	-6	.39	.11	.75	-.02	.71
Factor D: Scholastic Aptitude						
SAT-M (Mathematical)	8	-.10	-.01	.09	.96	.94
SAT-V (Verbal)	7	.10	.46	.38	.62	.68

Factor Correlations

	A	B	C	D
A	1.00	.00	.01	.00
B	.00	1.00	-.15	-.05
C	.01	-.15	1.00	.00
D	.00	-.05	.00	1.00

	A	B	C	D
PC Eigenvalues	2.40	1.97	1.62	1.13

(Analysis from Principal Components)

Analysis CORB (Cory, Rimland, & Bryson, 1977)

Loadings on Oblique Axes

		Factor								
		A	B	C	D	E	F	G	H	h^2
Factor A: Verbal/quantitative reasoning										
ARI (Arithmetic Reasoning)	3	.56	.09	.29	.18	.07	.08	-.03	-.06	.60
GCT (Verbal meanings)	2	.51	.18	-.04	.03	.37	.03	.14	.13	.68
AFQT (Vocab, arith reas.)	1	.49	.45	.02	.19	-.01	.11	.38	-.04	.75
Inference	17	.47	.02	.12	-.02	.42	-.01	-.02	.05	.54
ETST (Electron.Selectn)	8	.45	.26	.05	.23	.01	-.05	.06	.36	.57
Nonsense Syllogisms	16	.28	-.02	.03	.04	.20	-.07	.09	.02	.17
Factor B: Technical knowledge										
SHOP (Tools, etc.)	9	.00	.90	.05	.00	.21	.02	-.01	-.02	.97
MECH (Mechanical, elect.)	4	.13	.68	-.04	.11	-.02	-.02	.30	.05	.62
Factor C: Perceptual Speed										
CLER (Perceptual Speed)	5	.06	-.06	.71	-.07	.00	-.01	.08	.03	.59
Counting Numbers	12	-.06	.03	.63	.05	-.01	.07	-.01	.00	.42
Comparing Figures	19	-.04	.01	.39	.21	.09	-.02	.10	.08	.29
Hidden Patterns	11	.02	.08	.35	.25	.11	-.08	.35	.02	.43
-Year of Birth (=Youth)	-10	.00	.11	.32	.04	.18	-.08	-.03	-.10	.14
Factor D: (Auditory?) Associative Memory										
RADIO (Sounds, symbols)	7	.04	-.01	.26	.54	-.09	.02	-.01	.10	.47
SONAR (Pitch-memory)	6	-.04	.12	-.06	.38	.07	.03	.08	.04	.27
Visual Mem. for Numbers	22	-.07	-.02	.14	.26	.23	.23	-.11	-.12	.37
Factor E: Sequential Reasoning?										
Twelve Questions	20	.06	.04	-.01	.03	.42	.05	-.01	-.04	.27
Password	24	.02	-.04	.01	.02	.41	.08	.05	.06	.36
Object-Number	15	.12	-.21	.07	.05	.20	.01	-.02	-.16	.16
Factor F: Free Recall Memory										
Memory for Words	21	.02	.05	.02	-.03	.00	.71	-.01	-.01	.73
Memory for Objects	25	.01	-.04	-.09	.08	-.07	.42	.09	.11	.37
Factor G: Perceptual Closure										
Gestalt Completion	13	-.03	.03	.00	-.05	.05	.01	.64	.04	.48
Concealed Words	14	.02	-.08	.26	.01	-.13	.08	.40	-.06	.31
Drift Direction	18	.01	.05	.06	.18	-.06	.02	.19	.06	.10
Factor H: Pattern Perception										
Memory for Patterns	23	.02	-.02	.18	.35	-.01	.00	-.06	.48	.48
-Recognizing Objects	-26	-.01	.03	-.01	-.03	.02	.09	.24	.37	.34

Factor Correlations

A	1.00	-.04	.13	.18	.03	.09	.06	-.05
B	-.04	1.00	-.14	-.04	.04	-.17	-.11	.14
C	.13	-.14	1.00	.02	.02	.07	.09	.09
D	.18	-.04	.02	1.00	.21	.39	.18	-.06
E	.03	.04	.02	.21	1.00	.42	.28	.40
F	.09	-.17	.07	.39	.42	1.00	.22	.29
G	.06	-.11	.09	.18	.28	.22	1.00	.10
H	-.05	.14	.09	-.06	.40	.29	.10	1.00

PC Eigenvalues	5.33	2.41	1.80	1.48	1.35	1.22	1.08	.97
PF Eigenvalues	4.84	2.04	1.30	.91	.80	.69	.49	.42

Analysis EGAN (Egan, 1978)

Loadings on Orthogonal Axes

	Factor A	Factor B	Factor C	h^2
Factor A (Spatial Accuracy)				
LGZV Visualization: # Correct	.83	.00	.06	.69
GZAS Spatial Visualization	.78	.32	.01	.72
LBRT Block Rotation: # Correct	.77	.17	-.07	.62
GZAS Spatial Orientation	.76	.22	.06	.64
LSPA Spatial Apperception: # Correct	.67	.05	.05	.45
GZAS General Reasoning	.60	.03	.41	.53
GZAS Mechanical Knowledge	.50	.36	-.07	.39
Factor B (Spatial Speed)				
-LBRT Latency	.18	.88	-.00	.82
-LGZV Latency	.26	.84	.03	.77
-LSPA Latency	.00	.67	.33	.55
GZAS Perceptual Speed	.33	.42	.42	.47
Factor C (Doublet for *g*?)				
GZAS Numerical Operations	-.01	.00	.86	.74
GZAS Verbal Comprehension	.44	-.21	.41	.40

PC Eigenvalues: (not available from report)
Slight further rotation from Varimax Rotated Matrix

Analysis FERO (Fernandes & Rose, 1978)

Loadings on Oblique Axes

	Factor A		Factor B		h^2	
Day	1	2	1	2	1	2
Factor A: Free Recall (Secondary Memory) (?)						
Free Recall - % Correct, Control	.65	.94	.49	-.02	.67	1.00
List Differentiation,% Corr., 1	.59	.52	.01	.24	.35	.97
Factor B: Memory Span (Registration) (?)						
Memory Span - Ltrs, Low Sim.	.00	.35	1.00	.52	.99	.59
Running Recognition. # Cor./100	.42	.00	.31	.72	.28	.59
Situational Freq.,Correlation	.57	.34	.23	.50	.37	.55
Interference Suscept., % Cor.	.60	.33	.55	.49	.66	.52
Factor Correlations						
A	1.00	1.00	.00	.34		
B	.00	.34	1.00	1.00		
PC Eigenvalues	2.98	3.49	1.04	0.84		
PF Eigenvalues	2.59	3.12	.74	.59		

Analysis FRDB (Frederiksen, 1978)

Maximum Likelihood Loadings on Oblique Axes

		Factor					
		A	B	C	D	E	h^2
Factor A: Graphemic Encoding							
Letter Encoding	1	1.00	.00	.00	.00	.00	1.00
Scanning Speed	2	.64	.53	.00	.00	.00	.27
Factor B: Perceptual Facilitation in Encoding Multiletter Arrays							
Perceptual Facilitation	3	.00	.62	.00	.00	.00	.21
Bigram Probability	4	.00	.54	.00	.00	.00	.16
Factor C: Phonemic Translation							
Syllables: Pseudowords	6	.00	.00	.80	.00	.00	.39
Length: Pseudowords	5	.16	.00	.77	.00	.00	.40
Vowel: Pseudowords	7	.00	.00	.55	.00	.00	.16
Factor D: Automaticity of Articulation							
Syllable: Pseudowords(Dur.)	8	.00	.00	.00	.96	.00	.72
Vowel: Pseudowords (Dur.)	9	.00	.00	.00	.36	.00	.07
Factor E: Depth of Processing in Word Recognition							
Delta% Decoding: LFW-HFW	11	.00	.00	.00	.00	1.00	1.00
Delta% Decoding: Pseu.-HFW	10	.00	.00	.00	.00	.24	.03

Factor Correlations

A	1.00	-.32	.09	.58	-.11
B	-.32	1.00	.41	.24	.52
C	.09	.41	1.00	-.17	.08
D	.58	.24	-.17	1.00	.01
E	-.11	.52	.08	.01	1.00

Values taken from Frederiksen's Tables 4 and 5

Analysis HUFL (Hunt, Frost, & Lunneberg, 1973)

Loadings on Oblique Axes

		Factor					
		A	B	C	D	E	h^2
Factor A: Memory Span (Registration) (?)							
Clustering: Blocked Words	9	.82	-.10	.78	.02	.10	.94
Digit Span, 6-sec intervals	13	.80	.05	.11	.41	-.01	.91
Digit Span, 1-sec intervals	12	.62	.37	.01	-.28	-.06	.63
Factor B: Free Recall, Secondary Memory (?)							
No.Wds.Recalled,Unblocked	5	-.01	.87	.01	.04	.02	.82
Factor C: Slope of Visual/Memory Search (?)							
-Slope of memory scan	-10	-.12	.06	.59	.04	-.07	.59
Intercept, memory scan	11	.04	.50	.51	-.03	.23	.79
Factor D: Memory Span (Interference) (?)							
CVC Recall, # Correct	15	.54	-.08	.28	.66	.02	.76
No.Wds.Recalled,Blocked	6	-.26	.08	-.20	.62	-.02	.47
r: Param.of Contin.PA	1	.10	-.12	.28	.34	.20	.27
θ: " " " "	3	-.26	.29	.08	.30	-.16	.36
Factor E: Free Recall, Primary Memory (?)							
γ: Param.of Contin.PA	4	.02	-.03	-.01	-.04	.61	.38
α: " " " "	2	.49	.01	.01	.05	.53	.68
Clustering,Unblocked Wds.	8	.33	.18	.12	.28	-.45	.35

Factor Correlations

A	1.00	-.10	-.44	.01	.12
B	-.10	1.00	.23	.08	.07
C	-.44	.23	1.00	.02	.02
D	.01	.08	.02	1.00	.14
E	.12	.07	.02	.14	1.00

PC Eigenvalues	3.22	2.39	1.64	1.50	1.23
PF Eigenvalues	2.94	2.03	1.20	.99	.81

(R matrix singular; initial h^2 estimates were max. r's in array)

Analysis HULL (Hunt, Lunneborg & Lewis, 1975)

		Loadings on Orthogonal Axes					
		Factor					
	#	A	B	C	D	-E	h^2
Factor A: General Reasoning							
Sum+Tues:Additive const., T_2	27	.85	-.23	-.03	.10	.24	.81
" " :Days wt., T_2	-28	.83	-.08	.27	-.06	-.19	.81
" " :Carry wt., T_2	-34	.72	-.06	.17	.03	.20	.59
Verbal Reasoning	3	.70	.18	-.06	-.12	-.06	.54
Sum+Tues:A_2A_1 wt., T_2	-33	.65	-.38	-.25	-.21	-.18	.71
Space Visualization	1	.65	.17	.18	.03	-.09	.49
Sum+Tues:A_1A_2 wt., T_2	-32	.64	-.36	-.25	-.07	.33	.72
Numerical Reasoning	2	.56	.17	.55	-.20	.02	.69
Verbal Comprehension	4	.56	.35	-.18	-.30	-.13	.51
Numerical Ability	5	.53	.25	.38	-.18	.28	.60
Hidden Figures	8	.52	.08	.06	-.25	-.28	.42
Sum+Tues:Letters wt., T_1	-26	.48	.09	-.18	.06	-.19	.31
Digit Span (Auditory)	11	.29	.04	.20	-.22	.06	.18
Factor B: Perceptual Speed							
Clerical Speed: Names	7	.08	.68	-.14	-.02	.12	.37
Name—Physical Match Time	-15	.06	.61	-.03	.10	-.05	.38
Color Name—Asterisk Time	-13	.18	.61	.13	.15	-.01	.44
Clerical Speed: Numbers	6	-.26	.54	-.01	-.03	.07	.37
Sum+Tues:Month—Day wt., T_2	29	.20	-.36	-.03	.36	.16	.33
" " :Additive const, T_1	25	.02	.34	.20	.01	-.03	.16
Factor C: Slope of Visual/Memory Search (?)							
Dichotic Listening:Category	9	.29	-.07	.73	-.13	-.15	.66
Sum+Tues:Ltr—Mnth wt, T_2	-30	-.11	.34	.62	.26	-.10	.59
Dich.List;Ear—Cat.	-10	.07	-.21	.61	-.29	.00	.51
Slope, Mem.Scan, Pos.	21	.01	.07	.53	.29	-.01	.37
Slope, " " , Neg.	23	-.16	.03	.49	-.11	-.04	.27
Sum+Tues:A_2 wt., T_2	-31	.41	-.01	.49	.19	.11	.46
Factor D: Memory Span (Interference) (?)							
Transpositional Err.,Pos.4	18	-.13	-.05	-.12	.81	.06	.70
" Err., Pos.4-Pos.1	19	-.06	.14	.02	.76	-.07	.61
" " ,Pos.4-Nontr.	20	-.16	.13	.14	.72	-.08	.59
Asterisk Reading Time	12	.02	-.27	-.20	.29	.05	.20
Factor E: Speed of Mental Comparison (?)							
Iconic Mem: .3sec-Osec	17	-.16	-.14	.01	-.01	.72	.56
" Recall, Osec.Delay	16	.14	.36	.04	-.30	-.62	.63
Intercept,Mem.Scan, Neg.	-24	.06	.55	-.08	-.20	.59	.70
Physical Match Time	-14	.15	.23	.04	-.02	.56	.39
Intercept,Mem.Scan, Pos.	-22	.28	.46	-.09	-.08	.56	.62

Data rearranged, with sign reflections noted, from the authors' Table 9, Varimax Rotated Factor Matrix. Communalities computed from the data presented.

Analysis JAMA (Jackson & McClelland, 1979,
Table 1, p. 159)

Loadings on Orthogonal Factors

		Factor		
		A	B	h^2
Factor A: Verbal Comprehension				
Long passage:raw compreh.	7	.87	.06	.75
Short passage:raw compreh.	9	.70	.23	.54
Listening comprehension	3	.69	.31	.57
SCAT: Verbal Aptitude	4	.56	.35	.43
SCAT: Quant. Aptitude	5	.51	.15	.28
Factor B: Reading Speed				
Long passage: raw speed	6	.11	.93	.88
Short passage: " "	8	.25	.88	.84
Short passage:eff.rdg.speed	2	.54	.78	.91
Long passage:eff.rdg.speed	1	.66	.62	.82
PC Eigenvalues		5.15	1.41	
PF Eigenvalues		4.87	1.16	

Analysis JAMB (Jackson & McClelland, 1979,
Table 5, p. 167)

Loadings on Oblique Factors

		Factor				
		A	B	C	D	h^2
Factor A: Speed of Mental Comparison						
Physical-same letter match RT	9	.94	-.05	.06	.10	.92
Simple Pattern RT	8	.93	-.03	-.07	-.08	.87
Name-letter match RT	10	.85	.03	.33	-.10	.92
Synonym match RT	11	.79	.08	.22	.00	.73
Homonym match RT	12	.62	.03	.25	.08	.49
Auditory letter span	16	.35	.18	.00	-.28	.29
Factor B: Language Knowledge, Reading						
Listening Comprehension	3	.22	.80	-.07	.29	.69
Long passage:eff.rdg.speed	1	.37	.79	.11	.05	.83
Short passage: " " "	2	.38	.79	.17	-.06	.94
SCAT: Verbal Aptitude	4	.20	.59	.22	.05	.48
Accuracy, homonym task	13	-.13	.51	.02	-.31	.53
Factor C: Perceptual Speed (?)						
Multiple ltr. display Slope	15	.00	.00	.90	-.04	.83
" " " RT	14	.48	-.02	.74	.05	.86
SCAT: Quantitavie aptitude	5	.23	.33	.49	-.07	.47
Factor D: Visual Threshold						
Single letter threshold	7	.08	-.14	.31	.64	.66
Peripheral letter span	6	-.07	.11	.12	.46	.23

Factor Correlations

A	1.00	-.01	-.11	.02
B	-.01	1.00	.00	.34
C	-.11	.00	1.00	.00
D	.02	.34	.00	1.00

PC Eigenvalues	6.04	2.98	1.71	1.25
PF Eigenvalues	5.81	2.69	1.43	.82

Note: A graphically-rotated orthogonal solution is to be found in Table 6, p. 159.

Analysis JENS (Jensen, 1979)

Loadings on Orthogonal Factors

		Factor			
	±	A	B	C	h^2
Factor A: Slope of Choice Reaction Time per Bits					
Low slope of DT on bits	-2	.84	-.03	-.08	.71
Low slope, SD of DT on bits	-4	.65	.22	-.15	.50
Low mean SD of DT	-3	.54	.04	.30	[illegible]
Raven matrices, high score	9	.49	.43	.14	.45
High neuroticism	12	.08	-.01	[illegible]	.01
Factor B: General intelligence					
Concept Mastery,high score	10	.05	.86	.03	.75
Digit Span, high score	8	.02	.50	-.10	.26
Low extraversion	-11	.06	.30	-.01	.09
Low Lie scale	-13	-.03	.23	-.17	.06
Factor C: Hand Movement Speed					
High mean SD of MT	6	.02	-.02	.75	.57
Fast DT at 0 bits	-1	-.22	-.24	.64	.52
Fast mean Median MT	-5	.13	.18	.48	.28
Serial Learning,low errors	-7	-.02	.06	-.17	.03
PC Eigenvalues		2.61	2.00	1.53	
PF Eigenvalues		2.13	1.44	1.07	

Analysis LANA (Lansman, 1978,
Table 4, p. 56)

Loadings on orthogonal factors

		Factor			
		A	B	C	h^2
Factor A: Simple Reaction Time					
Probe RT: Easy recall	-2	.90	.41	-.05	.98
" " : Hard recall	-3	.86	-.09	.11	.76
" " : Control condition	-1	.50	.06	-.02	.25
Factor B: Paired Associate Learning (?)					
Cont.PA: p Correct, Hard rec.	7	.03	.80	.21	.69
" " " " , Easy "	6	.14	.69	.19	.54
Factor C: Memory span (Registration) (?)					
Digit span	8	.04	.12	.54	.31
WPC Verbal composite	9	-.02	.14	.54	.31
PC Eigenvalues		2.44	1.67	1.07	
PF Eigenvalues		2.14	1.23	.47	
Varimax factor variances		1.82	1.34	.68	

Analysis LANB (Lansman, 1978,
Table 6, p. 72)

Loadings on oblique factors

		Factor			
		A	B	C	h^2
Factor A: Speed of Semantic Processing					
Sent. Verif. RT, 6-item Cnd.	-5	.99	.04	.03	.98
" " ", 6-sec Cnd.	-8	.98	.07	.01	.97
" " " Control	-2	.96	.01	-.05	.93
Three-Term Series RT	-10	.73	.09	-.09	.55
WPC Verbal Composite	12	.59	.12	.20	.42
Factor B: Memory Span (Registration)					
Digit Recall, 6-item Cnd.	4	.07	.96	.01	.98
" " , 6-sec Cnd.	7	.01	.88	.06	.83
Digit Span	1	.11	.58	.14	.42
Factor C: Accuracy of Semantic Information Processing					
Sent. Verif. Errors, 6-item	-6	.01	-.01	.89	.82
" " " , 6-sec	-9	-.05	-.02	.86	.77
" " " , Control	-3	.02	.19	.71	.62
Three-Term Series Errors	-11	.23	.22	.26	.20

Factor Correlations

A	1.00	.00	.00
B	.00	1.00	.21
C	.00	.21	1.00

PC Eigenvalues	4.27	3.18	1.67
PF Eigenvalues	4.06	2.65	1.49

Analysis LUNA (Lunneborg, 1977,
Table 2, p. 314)

Loadings on Oblique Factors

		Factor			
		A	B	C	h^2
Factor A: Simple Reaction Time (?) or Slo e of CRT per bits?					
Motor RT	1	.78	.03	-.01	.77
Search intercept	6	.70	-.04	.23	.68
Choice time	2	.42	.18	.38	.49
Dichotic category	-9	.41	.33	-.01	.48
Search slope	5	.33	.07	.39	.34
Factor B: Free recall (?)					
Clustering base	11	.01	.89	.00	.98
Factor C: Memory Span (Registration) (?)					
Digit span final	-7	-.04	-.01	.58	.37
Prop. correct (CRT)	3	-.03	-.09	.46	.26
Stroop difference	4	.05	.18	.46	.25

Factor Correlations

A	1.00	.38	.11
B	.38	1.00	-.19
C	.11	-.19	1.00

PC Eigenvalues	3.23	1.73	.91
PF Eigenvalues	2.84	1.24	.54

Analysis LUNB (Lunneborg, 1977,
Table 5, p. 322)

Loadings on Orthogonal Factors

	Factor				
	A	B	C	D	h^2
Factor A: Slope of CRT per bits (?)					
Choice RT 2-finger	.93	-	-	-	-
Choice RT 1-finger	.71	-	-	-	-
Factor B: Speed of Semantic Processing (?)					
Raven Time I	-	.89	-	-	-
Raven Time II	-	.81	-	-	-
Factor C: Control of Articulation (?)					
Delay read time	-	-	.83	-	-
R/L latency	-	-	.68	-	-
Verbal prob. solv. intercept	-	-	.67	-	-
Factor D: Memory for complex events (?)					
Verbal prob. solv. slope	-	-	-	.81	-
No delay read time	.42	-	-	.64	-

Varimax-rotated principal component factors. Data re-arranged from author's Table 5. No loadings below .40 reported; communalities not reported.

Analysis MAUC (Malmi, Underwood, & Carroll, 1979)

Loadings on Oblique Factors

	A	B	h^2
Factor A: Free Recall (Secondary Memory)			
FRS	.49	-.06	.68
FR3	.48	-.03	.76
SL3	.45	.02	.77
SLS	.39	.05	.67
FR1	.34	.07	.59
SL1	.31	.06	.45
PAS	.24	.22	.69
Factor B: Paired Associate Learning			
PA-4St	-.05	.53	.84
PA-12St	.02	.48	.71
PA-2St	.02	.43	.89
PA1	.16	.35	.87
PA3	.10	.34	.66

Factor Correlations

A	1.00	.85
B	.85	1.00

PC Eigenvalues	8.34	.75
PF Eigenvalues	8.07	.49
Orthogonal Varimax Variances	4.33	4.24

Analysis ROBA (Robertson-Tchabo & Arenberg, 1976)

Loadings on Oblique Axes

	#	Factor A	B	C	D	E	h^2
Factor A: Simple Reaction Time							
Simple RT (onset of zero)	-4	.71	.00	.03	.03	.04	.66
Choice RT 1 (spec.digits)	-5	.69	.33	.00	.04	-.08	.81
Choice RT 2 (even[odd]digit	-6	.53	.47	-.01	.01	.08	.77
Factor B: RT to Complex Sequential Events							
Choice RT 4 (contig.digits)	-8	-.04	.81	.01	.07	-.02	.76
Choice RT 5 (even-odd seq.)	-7	.37	.55	.21	-.01	-.03	.75
Factor C: Accuracy of Complex Information Processing							
Choice RT 3: Correctness	11	-.02	-.02	.72	.02	.04	.74
Choice RT 4: Correctness	12	.03	.32	.64	-.02	-.05	.73
Factor D: Free Recall (Secondary Memory)							
Free Recall, 1st 7 pos'ns	10	-.01	.00	.01	.89	.00	.99
Delayed free recall	1	.09	.04	.04	.48	.30	.53
Digit span, longest span	2	-.14	.01	.24	.30	.05	.24
Factor E: Free Recall (Primary Memory)							
Free Recall, last 5 pos'ns	9	.00	.01	.00	.00	.70	.64
Dichotic digit pairs	3	.21	-.21	.04	.20	.26	.25
Delayed recognition	13	.24	-.08	.10	-.01	.26	.22
Factor Correlations							
	A	1.00	.23	.29	.31	.22	
	B	.23	1.00	.15	.21	.24	
	C	.29	.15	1.00	.34	.39	
	D	.31	.21	.34	1.00	.03	
	E	.22	.24	.39	.03	1.00	
PC Eigenvalues		4.83	1.65	1.30	1.13	.84	
PF Eigenvalues		4.53	1.31	.93	.82	.52	
Varimax Variances		2.53	1.60	1.51	1.48	1.09	

Analysis ROFE (Rose & Fernandes, 1977)

Loadings on Oblique Axes

Factor

	#	A		B		C		D		E		F		G		h^2	
Day		1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Factor A: Speed of Mental Comparison																	
Sternberg Intercept Pos.	15	.75	.81	-.16	-.03	-.19	-.22	-.12	-.02	.05	-.07	-.04	.10	-.12	-.04	.89	.95
Posner Physical Match Same	1	.43	.60	.14	-.07	.00	-.15	.04	.33	-.09	-.17	.01	-.01	-.02	.00	.70	.81
Posner "Different"	4	.32	.57	.11	-.03	.27	.16	.11	.19	-.12	.02	-.04	-.16	-.01	.05	.93	.85
Collins & Q.Superset Int.	31	.47	.55	.14	.32	.06	-.06	.22	.00	.14	.22	-.07	.08	.09	.06	.74	.78
Sternberg Intercept Neg.	17	.55	.54	-.06	.21	-.27	-.02	.10	-.15	-.24	.13	-.02	-.09	.18	.03	.75	.81
Posner Cat.Match-Same	3	.33	.53	.13	-.02	.22	.26	.10	.10	-.06	.07	.03	-.14	.14	.08	.80	.78
Posner Name Match-Same	2	.31	.39	.22	.21	.15	.01	-.08	.20	-.01	-.11	.03	-.03	.04	-.23	.80	.70
Factor B: Speed of Semantic Processing																	
Baron Sense-Nonsense	10	-.04	.00	.66	.82	-.14	-.04	.04	.02	-.02	.11	.11	.34	-.12	-.07	.95	.90
Baron Sense-Homophone	11	.00	-.03	.64	.75	-.13	.04	.07	-.29	-.02	.03	.19	.18	-.19	.03	.86	.92
Collins & Q.Property Int.	33	.16	-.05	.53	.74	-.11	-.07	.32	-.03	.17	.08	.07	.24	-.13	-.13	.82	.71
Baron Homophone-Nonsense	12	.07	.09	.47	.63	.02	.01	-.07	.06	-.02	.19	.07	.15	.05	-.02	.82	.78
Meyer "Word"	7	-.07	.14	.45	.46	.03	.20	-.13	.13	-.01	-.27	.01	.22	.13	-.05	.65	.83
Meyer "Non Word"	8	-.08	.18	.29	.44	.19	.15	-.32	.10	.02	-.05	-.21	.08	.02	-.06	.60	.70
Factor C: Slope of Visual/Memory Search																	
Sternberg Slope Positive	14	-.11	-.32	-.10	.19	.51	.60	.15	.16	-.22	.02	-.09	-.18	.08	.06	.70	.83
Sternberg Slope Negative	16	.02	.10	-.09	-.08	.72	.58	.00	.01	.20	.01	-.24	-.39	-.21	-.08	.76	.72
Clark & Chase "Base"	29	.10	.07	.30	.31	.22	.52	.01	.25	.19	.17	-.03	.05	.22	.07	.62	.84
Factor D: (Doublet for Juola Word Positive)																	
Juola Word Positive:Slope	18	.22	.17	.08	.09	.24	.15	.56	.74	.05	-.04	.13	.50	-.12	.06	.58	.68
" " " :Int.	19	.23	.07	.09	.22	.00	.00	-.49	-.64	-.21	-.32	-.09	-.19	.08	.02	.72	.81
Factor E: (Doublet for Juola Word Negative)																	
Juola Word Negative:Slope	20	.08	-.01	.12	.14	.26	.46	.21	-.15	.59	.60	-.03	-.49	.13	.02	.44	.88
" " " :Int.	21	.23	-.05	.00	-.06	-.05	.08	-.05	-.22	-.67	-.93	.18	.06	-.17	.01	1.00	.97
Factor F: (Doublet for Juola Category Positive)																	
Juola Cat. Positive:Slope	22	-.02	-.10	.28	.63	.04	-.15	.24	.14	-.15	-.17	.78	.60	.14	.17	.93	.75
" " " :Int.	23	.09	-.05	-.12	-.21	.08	.27	-.29	-.43	.00	.12	-.73	-.88	-.08	-.17	.86	.96
Factor G: (Doublet for Juola Category Negative)																	
Juola Cat. Negative:Slope	24	.08	.00	.08	.10	.12	.12	-.03	-.06	.09	-.05	.15	.23	.66	.80	.62	.92
" " " :Int.	25	-.05	-.01	.13	.17	.13	.07	.09	-.22	-.21	-.05	-.26	-.54	-.76	-.57	.93	.88
Factor Correlations																	
	A	1.00	1.00	.58	.18	.46	.47	-.16	-.28	-.34	-.05	-.07	.02	-.14	-.22		
	B	.58	.18	1.00	1.00	.53	-.18	.19	.60	-.65	-.53	-.45	-.76	.29	.60		
	C	.46	.47	.53	-.18	1.00	1.00	-.21	-.54	-.33	.20	.15	.53	-.03	-.51		
	D	-.16	-.27	.19	.60	-.21	-.54	1.00	1.00	-.38	-.43	-.65	-.78	.53	.69		
	E	-.34	-.05	-.65	-.53	-.33	.20	-.38	-.43	1.00	1.00	.58	.53	-.31	-.36		
	F	-.07	.02	-.45	-.76	.15	.53	-.65	-.78	.58	.53	1.00	1.00	-.51	-.71		
	G	-.14	-.22	.29	.60	-.03	-.51	.53	.69	-.31	-.36	-.51	-.71	1.00	1.00		
PC Eigenvalues		10.62	10.07	2.54	3.90	1.83	2.11	1.59	1.88	1.43	1.48	1.29	1.23	1.14	1.00		
PF Eigenvalues		10.41	9.88	2.33	3.73	1.66	1.99	1.34	1.72	1.12	1.33	1.02	1.09	.89	.82		

Loadings on oblique-axes produced by a Procrustes rotation using for the non-zero entries of the target matrix the average of "significant" loadings yielded by independent "blind" rotations of the respective data sets. No reflections of variables from the authors' correlation matrices were made.

Analysis ROSE (Rose, 1974)

Loadings on Oblique Axes

	r	A			B			C			D			E			h²		
Day		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Factor A: Stroop Reading Task																			
Stroop Color	-1	.87	.82	.78	.08	.09	.15	.05	.01	-.03	.36	.40	.56	-.02	.14	.22	.90	.81	.84
Stroop Color-Word	-2	.76	.86	.92	.00	.01	-.04	-.01	-.03	-.06	.36	.46	.54	-.03	.20	.12	.72	.90	.93
Factor B: Fine Motor Hand Control (?)																			
Letter-Search, Mean	-14	.34	.35	.41	.63	.48	.66	.03	.12	.07	.14	.14	-.03	.09	-.16	.00	.53	.42	.70
Tapping: Slope	-8	.15	.05	.07	.39	.45	.47	-.26	.03	-.07	.03	-.07	-.17	.07	-.32	-.01	.20	.23	.53
Tapping: Control	-7	.00	-.02	.08	.02	.35	.07	.01	-.03	.16	.08	-.09	-.15	.21	-.34	-.25	.22	.51	.66
Word Recognition Threshold	-12	.13	-.06	-.01	-.33	-.12	-.29	-.03	.18	.14	.04	-.19	-.12	-.06	.12	-.27	.15	.07	.46
Factor C: Simple Reaction Time (?)																			
Rotated Letters--Mean	-17	.01	-.03	-.17	.00	.00	.15	.69	.43	.65	.06	.11	.15	-.03	.05	.22	.54	.28	.77
Critical Tracking	-6	-.03	.15	.12	-.15	-.07	-.04	.35	.43	.55	-.03	.04	.05	.09	.22	-.04	.13	.29	.62
RT: Control	-10	.30	.15	.23	.00	.07	-.05	.35	.30	.41	-.05	-.08	-.06	-.02	.34	-.09	.22	.51	.60
Factor D: Verbal Ability																			
A-B Task	15	.03	.04	.10	.30	.14	.02	.09	-.03	.19	.63	.95	.58	-.11	.07	.55	.52	.99	.58
SAT	18	-.04	-.04	-.02	-.13	-.05	-.19	.00	.22	.08	.52	.29	.44	.00	.03	.32	.30	.22	.50
Contin.PA Mem.: # Correct	4	.07	-.11	.08	-.31	-.11	-.26	.16	.24	.09	.29	.27	.21	.16	.12	-.07	.26	.19	.64
Factor E: (Singlet for RT--Slope)																			
RT--Slope	-11	-.01	.12	.14	.11	-.14	.05	.04	.11	.06	-.07	.10	.42	.86	.21	.58	.75	.07	.40
Factor Correlations																			
	A	1.00	1.00	1.00	-.09	-.43	-.62	.00	.39	.08	.00	-.04	-.80	.08	-.41	.80			
	B	-.09	-.43	-.62	1.00	1.00	1.00	.24	-.48	-.02	-.05	-.20	.70	-.09	.87	-.70			
	C	.00	.39	.08	.24	-.48	-.02	1.00	1.00	1.00	.10	.25	.04	-.07	-.58	-.02			
	D	.00	-.04	-.80	-.05	-.20	.70	.10	.25	.04	1.00	1.00	1.00	.12	-.24	-.94			
	E	.08	-.41	.80	-.10	.87	-.70	-.07	-.58	-.02	.12	-.24	-.94	1.00	1.00	1.00			
FC Eigenvalues		2.50	2.64	2.76	1.53	1.58	1.78	1.41	1.28	1.43	1.25	1.22	1.20	1.19	1.01	1.07			
PF Eigenvalues		2.17	2.35	2.44	.90	1.03	1.17	.85	.77	.84	.80	.58	.62	.56	.38	.39			

Loadings on oblique axes produced by a Procrustean rotation using for the non-zero entries of the target matrix the average of "significant" loadings yielded by independent "blind rotations of the respective data sets.

Analysis UNBM (Underwood, Boruch, & Malmi, 1979)

		Oblique Factor Loadings						Schmid-Leiman Orthogonalized Loadings						
	#	A	B	C	D	E	h^2	g_m	a	b	c	d	e	h^2
Factor A: Free Recall														
FR-CO, Free Rec., Concrete	3	.58	-.01	-.02	.22	-.06	.67	.61	.51	-.01	-.02	.21	-.06	.69
FR-S, " ", Spaced/Massed	2	.55	-.02	.01	.07	.28	.73	.64	.49	-.01	.01	.06	.27	.73
FR-C, Free Recall, Control	1	.53	.06	.14	.01	.04	.65	.62	.48	.04	.14	.01	.04	.64
FR-AB, " " , Abstract	4	.41	-.01	.08	.41	-.04	.64	.59	.37	.00	.08	.39	-.04	.64
FR-II " " ,Ass.Pairs	5	.41	.08	-.03	.31	.01	.60	.62	.36	.06	-.02	.30	.01	.61
FR-CA " ",Cat'zd Lists	6	.37	.07	-.01	.29	.01	.50	.57	.33	.05	-.01	.27	.01	.51
LD List Discrimination	20	.37	.02	-.02	-.05	.32	.44	.46	.33	.01	-.02	-.05	.31	.44
SA-FR Simul.Acq, FR of pairs	25	.29	.04	.07	.02	.08	.22	.38	.26	.03	.07	.02	.07	.22
Factor B: Paired Associate Learning														
PA-II,PA:Crossed Associates	11	.02	.65	.03	-.01	-.04	.76	.76	.02	.50	.03	-.01	-.04	.82
PA-CA,PA:Paired Categories	12	-.02	.55	.07	.15	-.04	.66	.70	-.02	.43	.07	.14	-.04	.70
PA-M,PA: Matching	10	.03	.53	.00	.02	.10	.61	.69	.03	.40	.00	.02	.10	.65
PA-C,PA: Control	9	.16	.49	-.09	-.02	.03	.62	.69	.14	.38	-.08	-.02	.03	.65
SL-M,Serial Lrn'g,Matching	14	.12	.33	.04	.25	.03	.52	.63	.10	.25	.04	.24	.03	.53
SL-C, " " ,Control	13	.11	.28	.18	.14	.07	.42	.57	.10	.22	.18	.13	.06	.44
Factor C: Memory Span (Registration)														
MS-LL,Mem.Span,Low-sim.ltrs.	22	-.03	.03	.88	.01	.04	.83	.25	-.03	.02	.90	.01	.04	.84
MS-D, " " ,Digits	21	.03	-.02	.75	-.05	.06	.61	.19	.02	-.02	.75	-.05	.06	.61
MS-HL, " " ,Hi-sim.ltrs.	23	-.02	.12	.64	.04	-.08	.50	.27	-.02	.09	.64	.04	-.07	.50
Factor D: Memory for Events														
SF-Z Situat'l Freq.Judgment	19	.02	-.03	.05	.57	.31	.59	.40	.02	-.02	.05	.54	.30	.54
RR-D Running Recognition	18	.02	.04	-.02	.48	.27	.47	.40	.02	.03	-.02	.46	.26	.44
SA-D Simul.Acq.,Recog.Pairs	27	-.05	.10	.05	.40	.06	.26	.30	-.04	.07	.05	.38	.06	.24
Factor E: Verbal Discrimination														
VD-C Verb.Disc., Control	15	-.01	.10	.00	.06	.60	.49	.37	-.01	.08	.00	.06	.58	.48
VD-A " " , Affective	16	.12	-.01	.00	.07	.59	.50	.36	.10	-.01	.00	.07	.58	.48

Factor Correlations

						g_m
A	1.00	.62	.22	.28	.28	.73
B	.62	1.00	.16	.39	.30	.83
C	.22	.16	1.00	.19	.02	.24
D	.28	.39	.19	1.00	.20	.46
E	.28	.30	.02	.20	1.00	.37

PC Eigenvalues (Reported by authors)	8.41	2.13	1.46	1.30	1.14

Analysis SMML (Snow, Marshalek, & Lohman, 1976)

Loadings on Oblique Axes

		Factor						
		A	B	C	D	E	F	h^2
Factor A: (Uninterpreted)								
F2 [Raven, Wd. Trans.]	4	.58	.13	.00	.03	.01	-.02	.36
ST Vis.Mem.;F1	1	.42	-.10	.29	-.16	.14	.23	.39
Factor B: Slope of Visual/Memory Search (?), General Intelligence (?)								
SAT-Verbal	8	.02	.72	.35	.03	.01	-.01	.64
"Average Slope"	11	-.33	.68	.00	-.08	-.03	.02	.66
SAT-Quantitative	9	.25	.43	.35	.34	.34	.17	.56
Factor C: Speed of Mental Comparison (?)								
F1: "Space?"	3	.01	.02	.82	.08	.06	-.02	.70
"Average Intercept"	10	-.54	.01	.69	-.45	.00	-.29	1.00
Factor D: Memory Span, Registration								
Digit Span, Tot.Correct	21	.01	.04	.10	.88	.00	.06	.78
F4: Visual Mem. Span	6	.01	-.06	-.05	.88	.00	-.04	.83
Matching Fam. Figs. Time	13	-.22	.35	.00	.60	.12	.14	.52
Factor E: Perceptual Closure (?)								
F5: Perceptual Integration	7	.01	.00	.05	-.03	.60	.00	.36
Short-Term Visual Mem.:F2	2	.29	.28	.00	.35	.64	-.50	.87
Raven Time	12	-.02	-.02	-.30	.10	.33	.35	.29
Factor F: Perceptual Closure (?)								
F3: ("Perception?")	5	-.01	.30	.00	.15	-.01	.70	.71

Factor Correlations

A	1.00	.03	.05	.00	-.01	.00
B	.03	1.00	-.10	-.14	-.20	.20
C	.05	-.10	1.00	.00	-.11	.08
D	.00	-.14	.00	1.00	.04	-.06
E	-.01	-.20	-.11	.04	1.00	.00
F	.00	.20	.08	-.06	.00	1.00

PC Eigenvalues	2.96	2.26	1.76	1.58	1.26	1.08
PF Eigenvalues	2.71	1.92	1.42	1.17	.89	.57
Varimax Variances	2.35	1.58	1.53	1.16	1.04	.99

Analysis WHIA (Whitely, 1977,
Table 2, p. 471)

	Orthogonal Factors			
	A	B	C	h^2
Factor A: Speed of semantic processing (?)				
Relationship eduction (time)	.91	-.06	.21	.88
Short-term retention (time)	.67	.19	.14	.50
Analogy completion (time)	.45	.09	.09	.22
Factor B: Hand Movement Speed (?)				
Response execution (time)	.14	.98	.06	.98
Response decision (time)	.05	.76	-.01	.58
Factor C: Speed of semantic processing (?)				
Relationship study (time)	.13	-.04	.73	.55
Relationship evaluation (time)	.56	.01	.73	.85
Relationship choice (time)	.46	.04	.59	.56
Choice reaction time	-.11	.06	.13	.03
Proportion of common variance	.40	.31	.29	

Data rearranged from author's Table 2; Communalities computed from loadings given.

Analysis WHIB (Whitely, 1977,
Table 3, p. 472)

	Orthogonal Factors		
	A	B	h^2
Factor A: Accuracy of Semantic Processing (?)			
Analogy Completion after Study	.73	.02	.53
Relationship Evaluation	.72	.10	.53
Relationship Choice	.66	.17	.46
Short-term Retention	.32	-.02	.10
Factor B: (Uninterpreted)			
Response Decision	.50	-.56	.34
Relationship Education	.21	.41	.21
Proportion of Common variance	.78	.22	

Data rearranged from author's Table 3; communalities computed from loadings given.

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